TRANSACTIONS

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1945

SEVENTY-FIFTH ANNUAL VOLUME

Transactions

of the

American Fisheries Society

SEVENTY-FIFTH ANNUAL VOLUME

FOR THE YEAR 1945

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THE AMERICAN FISHERIES SOCIETY

Organized 1870 **Incorporated 1910**

The Society was organized to promote the cause of fish culture; to gather and diffuse information of a scientific character; and to unite and encourage those interested in fish culture and fishery problems.

STANDING COMMITTEES, 1945-1946

Executive Committee

The Executive Committee consists of the president, vice-presidents, secretary-treasurer, vice-presidents of divisions, and James Brown, the immediate past president.

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[1]Elected by the membership.
[2]Each member serves for 5 years; one new member is appointed each year by the incoming President.

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James A. Rodd	Ottawa, Ont.
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[a]Appointed by the President-elect, in accordance with a motion adopted by the membership.

PRESIDENTS' TERMS OF SERVICE AND PLACES OF MEETING

The first meeting of the Society occurred December 20, 1870. The organization then effected continued until February, 1872, when the second meeting was held. Since that time there has been a meeting each year, as shown below. The respective presidents were elected at the meeting, at the place, and for a period shown opposite their names, but they presided at the subsequent meeting.

1.	William Clift	1870-1872	New York, N. Y.
2.	William Clift	1872-1873	Albany, N. Y.
3.	William Clift	1873-1874	New York, N. Y.
4.	Robert B. Roosevelt	1874-1875	New York, N. Y.
5.	Robert B. Roosevelt	1875-1876	New York, N. Y.
6.	Robert B. Roosevelt	1876-1877[1]	New York, N. Y.
7.	Robert B. Roosevelt	1877-1878	New York, N. Y.
8.	Robert B. Roosevelt	1878-1879	New York, N. Y.
9.	Robert B. Roosevelt	1879-1880	New York, N. Y.
10.	Robert B. Roosevelt	1880-1881	New York, N. Y.
11.	Robert B. Roosevelt	1881-1882	New York, N. Y.
12.	George Shepard Page	1882-1883	New York, N. Y.
13.	James Benkard	1883-1884	New York, N. Y.
14.	Theodore Lyman	1884-1885	Washington, D. C.
15.	Marshall McDonald	1885-1886	Washington, D. C.
16.	W. M. Hudson	1886-1887	Chicago, Ill.
17.	William L. May	1887-1888	Washington, D. C.
18.	John Bissell	1888-1889	Detroit, Mich.
19.	Eugene G. Blackford	1889-1890	Philadelphia, Pa.
20.	Eugene G. Blackford	1890-1891	Put-in-Bay, Ohio
21.	James A. Henshall	1891-1892	Washington, D. C.
22.	Herschel Whitaker	1892-1893	New York, N. Y.
23.	Henry C. Ford	1893-1894	Chicago, Ill.
24.	William L. May	1894-1895	Philadelphia, Pa.
25.	L. D. Huntington	1895-1896	New York, N. Y.
26.	Herschel Whitaker	1896-1897	New York, N. Y.
27.	William L. May	1897-1898	Detroit, Mich.
28.	George F. Peabody	1898-1899	Omaha, Nebr.
29.	John W. Titcomb	1899-1900	Niagara Falls, N. Y.
30.	F. B. Dickerson	1900-1901	Woods Hole, Mass.
31.	E. E. Bryant	1901-1902	Milwaukee, Wis.
32.	George M. Bowers	1902-1903	Put-in-Bay, Ohio
33.	Frank N. Clark	1903-1904	Woods Hole, Mass.
34.	Henry T. Root	1904-1905	Atlantic City, N. J.
35.	C. D. Joslyn	1905-1906	White Sulphur Springs, W. Va

[1] A special meeting was held at the Centennial Grounds, Philadelphia, Pa., October 6 and 7, 1876.

36.	E. A. Birge	1906-1907	Grand Rapids, Mich.
37.	Hugh M. Smith	1907-1908	Erie, Pa.
38.	Tarleton H. Bean	1908-1909	Washington, D. C.
39.	Seymour Bower	1909-1910	Toledo, Ohio
40.	William E. Meehan	1910-1911	New York, N. Y.
41.	S. F. Fullerton	1911-1912	St. Louis, Mo.
42.	Charles H. Townsend	1912-1913	Denver, Colo.
43.	Henry B. Ward	1913-1914	Boston, Mass.
44.	Daniel B. Fearing	1914-1915	Washington, D. C.
45.	Jacob Reighard	1915-1916	San Francisco, Calif.
46.	George W. Field	1916-1917	New Orleans, La.
47.	Henry O'Malley	1917-1918	St. Paul, Minn.
48.	M. L. Alexander	1918-1919	New York, N. Y.
49.	Carlos Avery	1919-1920	Louisville, Ky.
50.	Nathan R. Buller	1920-1921	Ottawa, Canada
51.	William E. Barber	1921-1922	Allentown, Pa.
52.	Glen C. Leach	1922-1923	Madison, Wis.
53.	George C. Embody	1923-1924	St. Louis, Mo.
54.	Eben W. Cobb	1924-1925	Quebec, Canada
55.	Charles O. Hayford	1925-1926	Denver, Colo.
56.	John W. Titcomb	1926-1927	Mobile, Ala.
57.	Emmeline Moore	1927-1928	Hartford, Conn.
58.	C. F. Culler	1928-1929	Seattle, Wash.
59.	David L. Belding	1929-1930	Minneapolis, Minn.
60.	E. Lee LeCompte	1930-1931	Toronto, Canada
61.	James A. Rodd	1931-1932	Hot Springs, Ark.
62.	H. S. Davis	1932-1933	Baltimore, Md.
63.	Fred A. Westerman	1933-1934	Columbus, Ohio
64.	E. L. Wickliff	1934-1935	Montreal, Canada
65.	Frank T. Bell	1935-1936	Tulsa, Okla.
66.	A. G. Huntsman	1936-1937	Grand Rapids, Mich.
67.	I. T. Quinn	1937-1938	Mexico City, Mexico
68.	Fred J. Foster	1938-1939	Asheville, N. C.
69.	T. H. Langlois	1939-1940	San Francisco, Calif.
70.	James Brown	1940-1941	Toronto, Canada
71.	John Van Oosten	1941-1942	St. Louis, Mo.
72.	John Van Oosten	1942-1943	(No meeting.)[2]
73.	John Van Oosten	1943-1944	(No meeting.)[3]
74.	John Van Oosten	1943-1944	(No meeting.)[3]
75.	John Van Oosten	1944-1945	(No meeting.)[3]

[2]The annual meeting scheduled to be held in New Orleans, La., was cancelled because of the war emergency.

[3]No annual meeting scheduled because of the war.

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PRESIDENT'S MESSAGE

THE AMERICAN FISHERIES SOCIETY—ITS 75TH ANNIVERSARY

JOHN VAN OOSTEN, *President*

It is unfortunate that conditions created by the war again forced the postponement of the annual meeting of our Society. The cancellation in 1945 was especially ill-timed since this year happened to be the 75th anniversary of the Society. This important milestone in the existence of our Society should not be passed unnoticed. Since the presentation of a program in commemoration of this event is impossible in the absence of a meeting, it would seem to be most appropriate for me to review briefly at this time the history, the objectives, and the organization of the Society. Such a resumé will no doubt interest our younger members as well as any new or prospective members, and will also refresh the memories of our older colleagues.

The American Fisheries Society is, I believe, the oldest organization of its kind in the Western Hemisphere. It originated as the American Fish Culturists' Association which was formed at a meeting held in New York City on December 20, 1870, in response to a call issued November 1, 1870, by W. Clift, A. S. Collins, J. H. Slack, F. Mather, and L. Stone. The primary objective was to promote the cause of fish culture. The first regular annual meeting with a formal program was held in Albany, New York, on February 7 and 8, 1872.

On February 28, 1878, the Society modified its name to the American Fish Cultural Association and broadened its scope to include all questions of a scientific and economic character that pertained to fish. On May 14, 1884, the name was changed to The American Fisheries Society and on December 16, 1910, the Society was incorporated in the District of Columbia as the American Fisheries Society. On September 11, 1935, the objectives were again broadened to include all fishery problems. These revised objectives, which are in effect today, are stated as follows: "The objects of the Society shall be to promote the cause of fish culture and its allied interests; to gather and diffuse information on all questions pertaining to fish culture, fish, and fisheries; and to unite and encourage those interested in fish culture and fisheries problems."

The American Fisheries Society has expanded into an international association including members from the United States, Canada, Mexico, and other countries. Its interests now cover every phase of the fisheries, and among its members are found, therefore, fishery administrators, fish-culturists, biologists, technologists, conservationists, sportsmen, and commercial fishermen. Anyone interested in fish and fisheries is now eligible to membership.

The Society convenes once a year, usually in September. The places of the meetings are rotated among the different sections of the country.

Five conventions have been held in Canada, one in Mexico, and the rest in the United States. The proceedings of the meetings and the papers presented at them are published in a single volume, the *Transactions of the American Fisheries Society.* Although no meeting has been held since August 1941 because of the war, the Society has nevertheless continued to publish the *Transactions.* In no other single publication can be followed so completely the history of the development and the progress in North America of fish culture, fishery research, and fishery management and conservation from the earliest years to the present. As a rule, reports on new developments in and new contributions to fish culture, and fishery management and conservation make their first appearance in *Transactions.* No fishery worker can keep himself informed adequately without access to this publication.

The elected officers of the Society include a president, first vice-president, second vice-president, secretary-treasurer, and librarian. In addition there are five elected vice-presidents of divisions which are designated as follows: Fish Culture, Commercial Fishing, Aquatic Biology and Physics, Angling, and Protection and Legislation. All of these elected officials together with the last preceding president constitute the Executive Committee. The other four standing committees are those on: International Relations, State and National Relations, Common and Scientific Names of Fishes, and Publications. In addition there is a special Committee on Pollution Study. At each annual meeting the vice-presidents of the five divisions and the chairmen of the different committees report upon the events and developments that have occurred in their particular fields during the past year. These reports constitute a valuable resumé of progress in these various branches of the fisheries. In addition to the publication of these reports, resolutions are also adopted by the Society to express its views on any important fishery questions of national and international scope.

As new and specific problems of widespread interest arise or develop, new committees to study these problems are appointed either as special or as standing committees depending more or less upon the permanency of the question under consideration. One of the most important of such special committees in recent years was the Committee on American Fish Policy. This committee completed its work with the adoption by the Society of the North American Fish Policy in June 1938. This Policy corresponds to the American Game Policy adopted in 1930 by the former American Game Association. The North American Fish Policy has had considerable influence in shaping the programs of many conservation departments. The Committee on Common and Scientific Names of Fishes, although appointed for a specific purpose, is a standing committee. Its principal function is to prepare a list of standard common names of fishes for universal adoption and to keep this list up to date. This committee's work has

not yet been completed although its members have already agreed on the appropriate common and scientific names of many species of fish. It is hoped that when the Society finally adopts an official list of names, it will ultimately be accepted by all writers, federal, state and provincial departments, organizations, and the general public. By the wide acceptance of such a list, the tremendous amount of confusion in the use of common names of fishes should be eliminated to a large extent.

The Society is financed entirely by membership dues. At the present time (1945) the membership is abnormally low because of the war. The normal enrollment exceeds 800 and encompasses the following classes of membership: patrons, life members, active members, state members, club members, libraries, foreign corresponding members, and honorary members.

PAPERS

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THE LAKE TROUT FISHERY IN ALGONQUIN PARK FROM 1936 TO 1945

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AND

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ABSTRACT

The average lengths of lake trout (*Cristivomer namaycush*) captured in the various Algonquin Park lakes during the decade varied from 13.3 to 24.8 inches and the number captured per 100 boat-hours from 39 to 154. When the average length of fish captured is plotted against number captured per unit effort, all the points fall below a line which begins at a length of 13.3 inches with an availability of 220, rises to an availability of 355 at 15.5 inches, and drops lower as the size increases until at 24 inches the line falls below 100 fish per hour. This line has been taken as the standard for availability of lake trout in Algonquin Park and a fishing index has been proposed which compares each fishery with this standard curve. Certain lakes have shown marked annual fluctuations in size and abundance of lake trout that suggest the progression of major year classes through the fisheries. More detailed examination of the catch statistics indicates that an extremely uneven success of year classes of lake trout appears to be universal in the Algonquin Park lakes.

INTRODUCTION

With the completion of the tenth year of the Algonquin Park creel census, it was felt that sufficient material had been accumulated to warrant a compilation of the data in order to discover what trends the lake trout fisheries had taken over that period, and to see whether the conclusions drawn from the two preliminary analyses (Fry and Kennedy, 1937; Fry, 1939) had been substantiated by subsequent developments.

Algonquin Park has an area of approximately 2,700 square miles and is situated in the Precambrian shield with the parallels 45° 45′ N. and 78° 30′ W. intersecting near its center. There are about 200 lakes which support populations of game fish. The largest of these is Lake Opeongo with an area of 20.1 square miles, and there are about 15 lakes with areas from 5 to 15 square miles. The majority of the lakes which sustain lake trout fishing are from 100 to 1,000 acres. Lake trout populations occur in a few lakes as small as 30 acres.

The method of conducting the Algonquin Park creel census was described by Fry (1939). Major emphasis has been placed on the collection of statistics concerning the size composition and fishing effort rather than the total catch. Thus, for most lakes, we have de-

scriptions of the fishery based on samples of the catch rather than statistics of production derived from a measurement of the total yield. In certain lakes where the circumstances permitted a more complete census, as in Opeongo, statistics for the production of the fishery have also been obtained.

The present report deals with the lake trout, which is the most important game fish in the Park. The speckled trout (*Salvelinus fontinalis*) and the smallmouth black bass (*Micropterus dolomieu*) are second in importance, and the statistics for these, it is hoped, will be the subject of subsequent analyses. In addition to the above species, northern pike (*Esox lucius*), pikeperch (*Stizostedian vitreum*), and the maskinonge (*Esox masquinongy*) are captured in a limited region in the northwest corner of the Park.

The Standard Profile of Availability

In studying the lake trout fishery in Algonquin Park over the last 10 years, it becomes obvious that there has been extreme variation not only in the size of the lake trout captured in one lake from year to year, and between all the lakes in the Park, but also in the number of fish caught per 100 boat-hours, or "availability" of the fish. A comparison can be made between the lakes by reference to Table 1, which presents a synopsis of the years 1939 to 1945. The data for the years 1936 to 1938 have already been published by Fry (1939).

Extreme as the afore-mentioned variations have been, all the lakes for which the data are sufficiently complete fit into the picture of the trout fishery of the Park described by Fry (1939) which was briefly: that for all the lakes covered by the records of those three years a contour line could be drawn describing the limits of their potential, and, that most of the lakes would fall beneath this profile of perfection. With the intention of analysing the figures for the last 10 years, we have employed the same pattern by constructing Figure 1 which relates the average length with the number captured per 100 boat-hours for all the lakes with records for 50 or more fish (data from Table 1). This graph also includes those lakes from 1936 to 1938 plotted on a similar graph by Fry (1939, Figure 12). The more extensive information covering the last seven years, confirms in all its major points the picture presented in 1939, and perhaps that interpretation may now be considered valid. However, one slight modification has been made, *viz.:* that the peak availability of 426 based on the record of 17 fish for Cradle Lake 1938, has proven too extreme, so that a peak of 355 is sufficient to enclose the later records. From Figure 1 it will be noted that most of the lakes still fall below the boundary line, which we term the standard profile of availability, beginning at 220 availability and running through 355 to reach a lower availability as the average annual length increases towards 24 inches. As on the graph printed in 1939, there is a small group of lakes (circled)

TABLE 1.—*Synopsis of creel-census returns for lake trout captured in various Algonquin Park lakes in the years 1939-1945*

[The unit for fishing effort is based on two men in one boat. Lengths were measured to the fork of the tail.]

Name of lake	1939			1940			1941		
	Number of fish reported	Average length (inches)	Number of fish per 100 hours	Number of fish reported	Average length (inches)	Number of fish per 100 hours	Number of fish reported	Average length (inches)	Number of fish per 100 hours
Big Crow	86	20.4	145	46	18.7	180	......	......	......
Big Trout	51	20.7	93	52	21.7	200	35	21.5	206
Black Bear	74	24.8	80	13	19.6	130	9	15.7	100
Burnt Island	479	24.7	78	21	23.8	75	87	15.6	63
Butt	263	16.4	170	338	16.1	320	Closed		
Cache	93	15.5	52	52	15.7	79	68	14.9	77
Canisbay	74	14.7	126	Closed			27	14.7	93
Canoe	38	28.4	86	19	22.7	90	2	23.0	80
Cedar	12	......	75	......	......	......	1	......	200
Crooked	96	16.4	148	......	......	......	......	......	......
Delano	9	......	......	......	......	......	43	15.2	210
Dickson	23	22.2	77	11	......	......	52	19.8	87
Happyisle	73	18.5	120	76	15.7	144	50	16.7	100
Harness	......	......	......	21	14.0	155	14	14.7	113
Head	Closed			105	15.1	177	Closed		
La Muir	64	22.8	94	9	26.1	170	6	......	120
La Vieille	......	......	......	24	19.0	......	282	19.2	187
Little Island	44	15.2	93	Closed			99	17.1	130
Louisa	373	14.2	219	320	15.2	191	153	15.6	163
MacIntosh	40	17.8	114	......	......	......	10	18.0	286
Merchant	......	......	......	137	16.8	182	Closed		
North Tea	......	......	......	13	......	100	1	......	......
Opeongo	1,233	18.4	112	1,133	17.9	120	885	17.4	97
Penn	54	17.0	60	......	......	......	7	24.0	100
Proulx	107	23.7	73	15	23.3	73	Closed		
Ragged	65	20.6	92	Closed			20	18.2	95
Red Rock	331	18.1	113	Closed			216	17.9	120
Rock	84	17.2	90	24	......	77	6	......	120
Smoke	224	21.7	51	167	20.0	81	64	17.9	106
Source	49	13.6	160	......	......	......	85	13.5	44
Tanamakoon	13	13.2	70	51	......	160	16	14.0	62
Two Rivers	18	16.8	82	121	15.7	117	2	18.0	50
Whitefish	16	15.5	76	2	22.0	......	6	21.0	34

Name of lake	1942			1943			1944			1945		
	Number of fish reported	Average length (inches)	Number of fish per 100 hours	Number of fish reported	Average length (inches)	Number of fish per 100 hours	Number of fish reported	Average length (inches)	Number of fish per 100 hours	Number of fish reported	Average length (inches)	Number of fish per 100 hours
Big Crow	43	21.3	83	44	20.0	142	23	19.7	115	14	15.9	101
Big Trout	42	16.9	200	41	21.2	300	40	21.3	115	46	23.3	128
Black Bear	27	18.0	159	32	15.8	300	......	......	......	126	21.5	58
Burnt Island	62	21.6	102	23	21.1	70	197	19.0	127	80	19.9	135
Butt	154	......	270	Closed			17	19.2	225	Closed		
Cache	80	15.3	89	125	14.7	92	127	15.5	116	101	15.2	81
Canisbay	Closed			229	14.1	181	Closed			214	14.4	143
Canoe	3	29.1	100	1	......	......	5	14.4	......	57	20.8	135
Cedar	......	......	......	59	20.1	95	136	18.0	99	......	......	......
Crooked	38	17.3	192	94	16.5	176	29	17.0	170	3	18.3	100
Delano	Closed			146	13.5	267	Closed			94	14.0	157
Dickson	38	20.6	130	41	22.2	142	78	19.7	85	37	18.0	104
Happyisle	77	15.9	183	75	15.0	139	78	17.1	97	21	17.6	85
Harness	Closed			64	15.0	205	Closed			20	18.6	99
Head	169	16.0	130	Closed			76	15.4	118	Closed		
La Muir	......	......	......	35	19.8	194	91	21.8	197	44	21.2	134
La Vieille	62	17.5	204	16	18.2	266	95	20.6	107	200	19.8	143
Little Island	Closed			125	14.8	135	Closed			95	18.2	80
Louisa	180	16.8	310	193	14.0	280	156	15.5	197	343	15.4	258
MacIntosh	Closed			......	......	......	Closed			68	18.2	131
Merchant	97	17.7	201	Closed			131	17.2	106	Closed		
North Tea	......	......	......	86	21.7	127	82	19.4	169	......	......	......
Opeongo	504	18.5	111	704	18.4	126	835	18.8	126	1,139	19.7	101
Penn	Closed			13	......	......	Closed			100	17.6	139
Proulx	......	......	......	Closed			31	23.9	63	Closed		
Ragged	Closed			79	19.8	99	Closed			77	19.0	74
Red Rock	Closed			87	18.7	153	Closed			78	17.4	69
Rock	36	15.9	130	......	......	......	......	......	......	33	14.5	85
Smoke	37	19.2	120	50	18.5	129	86	18.7	124	254	18.6	94
Source	59	14.6	53	201	15.7	50	58	18.0	39	74	16.1	81
Tanamakoon	50	13.3	86	10	14.0	125	14	16.5	73	125	14.4	96
Two Rivers	38	15.6	107	71	17.3	117	90	18.0	124	125	17.8	101
Whitefish	16	18.1	134	......	......	......	4	16.6	200	84	17.4	89

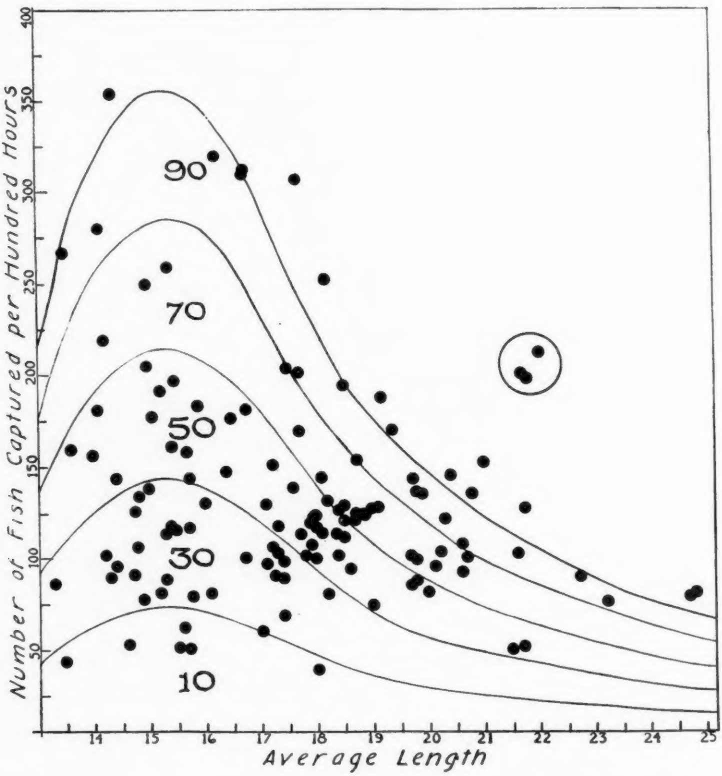

FIGURE 1.—The relationship between number of lake trout taken per 100 boat-hours (availability) and the average fork length of lake trout captured in Algonquin Park lakes. Data from Table 1. Only records based on more than 50 fish are plotted.

clustered around the junction of the 200-availability line and the 22-inch line, which indicate far better fishing. Again we feel that since the fishing season is shorter and since the lakes are not fished so intensely, Hogan 1937, Big Trout 1940, and La Muir 1944 do not fall into the general pattern.

The explanation offered for this general pattern is briefly, that there are three factors which influence the Algonquin Park fishery. These factors are fishing pressure, variations in the size at maturity, and the rate at which the larger fish consume the smaller trout.

Fishing, in addition to natural mortality, reduces the average age and size of a lake trout population. In a lake where the lake trout mature at a small size, heavy fishing by the tackle now in use, will not deplete the stock entirely. A sufficient number will be left to spawn and the fishery will be perpetuated. When judged by their availability, lakes in which the average length of the trout is about 16 inches and which contain substantial numbers of mature fish have the densest trout population.

An Index for the Lake Trout Fishery

The general classification, founded on the two variables, length and availability, offers a rational basis for grouping the lake trout fisheries. But a more convenient and practical evaluation of changes in the quailty of the fisheries would be based on an index of one variable. Such an index is possible if the theory is accepted that all populations tend toward their ultimate potential if permitted to do so, and that the potential for all lakes would be a series of points on the boundary curve. Therefore, a lake on the standard profile of availability might be considered, under the fishing conditions of Algonquin Park, to have the best possible fishing and to be at 100 percent of perfection. Some confusion might be caused by the exclusion of 11 recordings, exclusive of those circled, which are not encompassed by the 100-percent line. These data were intentionally excluded since it was thought best to make the standard something below the extremes encountered. This action is admittedly arbitrary.

Just as lakes on the standard profile of availability can be considered at 100 percent of perfection, so are lakes beneath that curve at various lower percentages of perfection. Contour lines at 20-percent intervals have been plotted on Figure 1 for what might be termed particular percentages of perfection. Each section thus divided is labelled at the mean percentage of that section, so that all lakes lying within zero and 20 percent are considered at 10 percent of perfection, those between 20 percent and 40 percent are rated at 30 percent of their potential, and so on. It would be simple to subdivide the graph still further, but neither the data nor the results warrant such a division. More lakes lie between the 40-percent and 60-percent contours than within any of the other zones and approximately two-thirds of the records lie between the 20-percent and 80-percent contours.

In Table 2 we have assigned those lakes for which we have records of 25 or more fish a year and which yield 50 or more fish in some years, to their percentage zones. It demonstrates at what percentage of perfection was the annual catch from each lake. While the table includes only a few lakes, there are sufficient to indicate a remarkable variation from year to year in some lakes, and but slight alteration in others. For example, the index for Louisa varied from 110 in 1938 to 50 in 1940; Opeongo dropped from 70 in 1936 to a low of 30 in 1941

TABLE 2.—*Quality of lake trout fishing in various Algonquin Park lakes, 1936-1945, as measured by the fishing index proposed in the text*

Name of lake	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945
Big Trout	....	110	....	70	110	110	70	110	90	110
Burnt Island	....	....	....	110	90	10	90	50	70	90
Cache	....	30	30	10	30	30	30	30	30	30
Canisbay	....	....	50	30	Closed	30	Closed	50	Closed	50
Dickson	....	110	....	70	....	50	90	110	50	50
Happyisle	....	70	50	50	50	30	50	30	30	30
Head	....	50	30	Closed	50	Closed	30	Closed	30	Closed
La Vieille	....	90	70	....	....	110	70	110	90	90
Little Island..	....	....	30	30	Closed	50	Closed	30	Closed	30
Louisa	....	70	110	70	50	50	90	90	50	70
Merchant	....	90	90	....	50	....	70	Closed	30	Closed
Opeongo	70	70	50	50	50	30	50	70	70	70
Proulx	....	90	90	90	90	Closed	....	Closed	70	Closed
Ragged	....	30	Closed	70	Closed	50	Closed	70	Closed	50
Red Rock	70	70	Closed	50	Closed	50	Closed	70	Closed	30
Smoke	....	50	50	50	50	50	70	70	70	50
Source	....	30	30	30	....	10	10	10	10	30
Tanamakoon..	....	....	30	30	....	10	30	30	30	30
Two Rivers ..	....	30	....	30	30	30	30	50	50	50

and rose again to 70 in 1945; Red Rock has fluctuated between 70 and 30; and Cache remained static at 30, except for 1939 when it dropped to 10 percent. Cache, then, will be found on Figure 1 between the 20-percent and 40-percent contours according to the average length per annum.

FLUCTUATION IN LOUISA LAKE

Louisa Lake provides the most striking example of fluctuation from year to year in an individual lake. During the 10-year period the fishery has failed, has recuperated and has failed again. The course of these changes is shown in Figure 2 where the availability is plotted against the average annual length. Whereas Table 2, which shows Louisa lake changing from 110 to 50, can indicate only the extent of the flux, this graph gives direction as well as extent. It is a picture of the increase or decrease in the average length of the fish caught, plotted against the increase or decrease in the availability. In 1937, the availability was 240 and the average length was 16.7 inches. In 1938 the availability rose to 355, but the average length decreased to 14.4 inches. The following year the availability had fallen to 219 but the average length remained approximately the same. Continuing the line around, it becomes apparent that there is a marked pattern of two cycles in the period. The year 1942 corresponds to 1937 with a high average length, but 1943 returns to a low average length. The years 1944 and 1945 are continuing a third cycle. While this cycle appears definite in Louisa, it is not at all certain that we should expect its continuation. (Figures for 1946 seem to indicate a variation in the cycle, since the availability reached an all-time low at 98 with the average annual length at 14.5 inches.) However, whether the cycle is regular or not, the data strongly suggest a progression of at least two major year classes through the fishery.

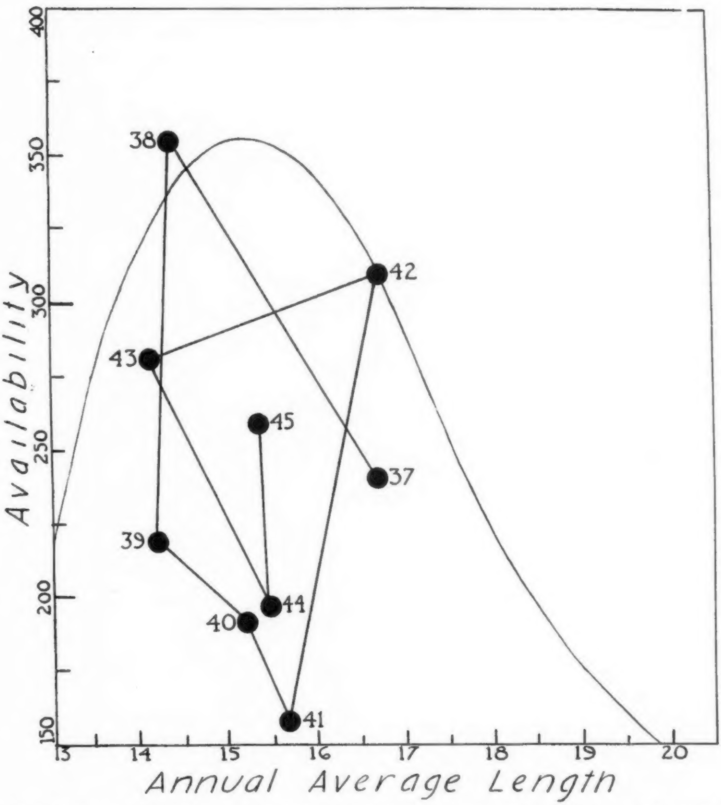

FIGURE 2.—Annual changes in average fork length and availability in lake trout captured in Lake Louisa.

YEAR-CLASS VARIATION IN LAKE TROUT POPULATIONS

Figures for Lake Louisa lack detail to demonstrate the fluctuation in the year classes as they progress through the fishery, but an exceedingly clear example of both successful and unsuccessful year classes passing through can be seen in the records for Merchant lake. Figure 3 is a comparison between the availability data according to length for the years 1940 and 1942, the lake being closed to fishing in 1941. In 1940, the peak availability occurred at 18 inches. In 1942 the highest availability had shifted to 37.7 at 19 inches. Moreover, there was a complete shift of the whole availability curve with the size

classes under 19 inches having a lower availability than in 1940 while the classes above 18 inches had a higher availability, except for the largest size classes. Evidently the successful year class which had a modal length of 18 inches in 1940, had grown to 19 inches in 1942. In addition, the fact that the 1942 graph begins at 14 inches instead of 13 inches, as in 1940, and the fact that the fish from 15 inches to 18 inches in 1942 do not reach so high an availability as in the previous fishing year, indicate that there was a year-class failure. In short, if the procession of year classes had all been of equal strength, the picture would have been approximately the same for both years, or

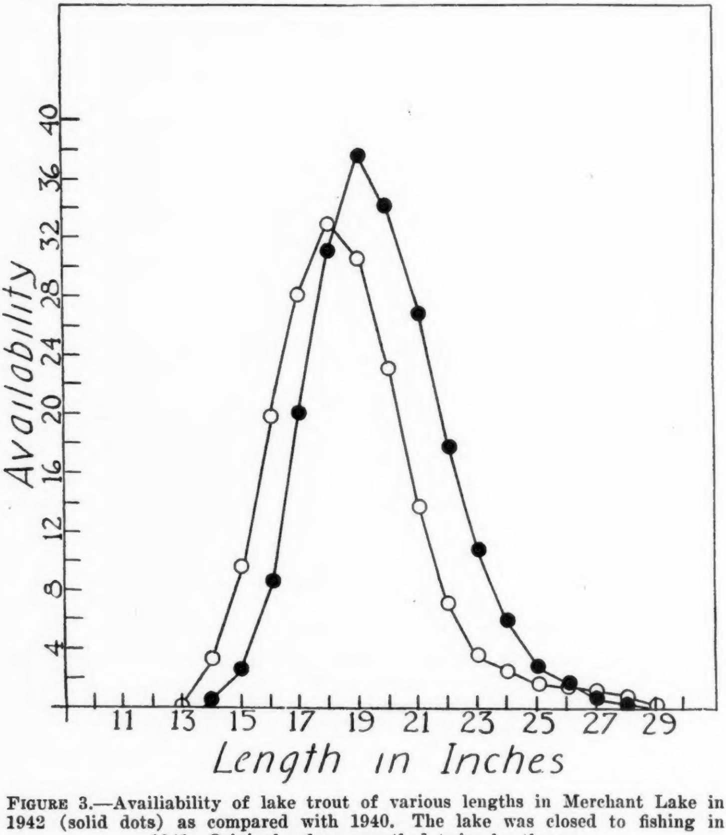

FIGURE 3.—Availiability of lake trout of various lengths in Merchant Lake in 1942 (solid dots) as compared with 1940. The lake was closed to fishing in 1941. Original values smoothed twice by threes.

rather, since a year of closure intervened, there should even have been a further reinforcement of the small size classes.

Although Figure 3 clearly illustrates a relationship in the fishery for 2 years, the parade of year classes through the various lakes from the time they enter the fishery to the time they are finally exterminated can be displayed more distinctly by relating each year to the 10 years covered in this survey. Figures 4-8 illustrate what appear to be numerous examples of the fluctuation of year-class strength in lake trout populations.

These histograms demonstrate the difference between the availabilty of each size class for one year and the average availability for each size for the 10 years. It should be borne in mind that these figures are not a direct indication of the abundance of fish in a lake, but only give a measure of the angling success—a datum which is influenced by meteorological conditions, by the skill of the angler and by fishing pressure, as well as by the abundance of fish in the lake. Nevertheless, availability can be taken as a measure of abundance for all but minor annual fluctuations. Whether the figures are influenced by the fishing conditions or not, it is obvious that year classes which enter

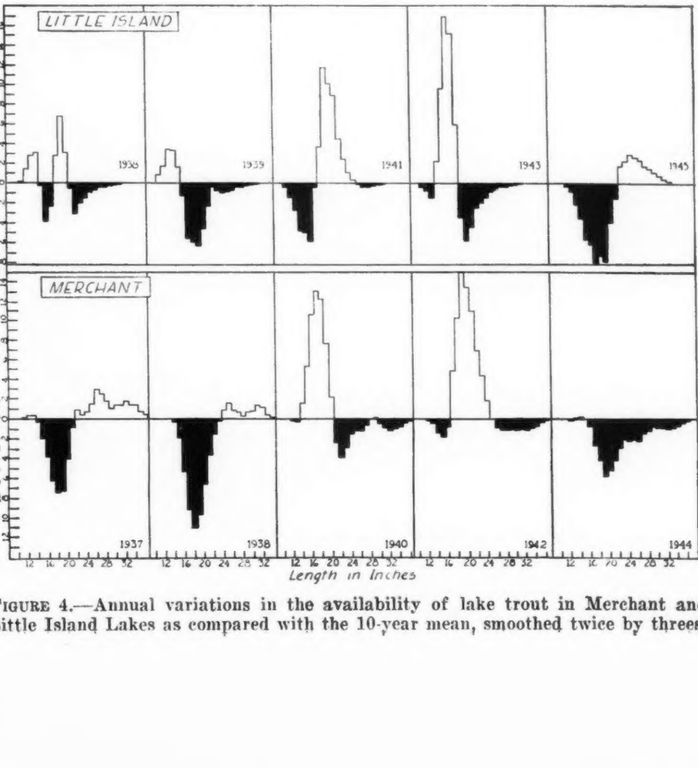

FIGURE 4.—Annual variations in the availability of lake trout in Merchant and Little Island Lakes as compared with the 10-year mean, smoothed twice by threes.

below the average availability, without recovering within a year or two, give evidence of year-class failures.

The graph for Merchant Lake (Figure 4) further demonstrates the success of one year class, and the failure of the subsequent year class. In Merchant Lake for 1937, there was a slight advantage over the 10-year mean in the 12- and 13-inch sizes, followed by a decrease in those from 14 inches to 19 inches. The availability of sizes from 22 to 32 inches was higher than the average. In 1938 the availability of all sizes up to and including 23 inches dropped sharply. A minor increase occurred for those from 24 to 32 inches, but even these had decreased below the 1937 level. Thus, the two years 1937 and 1938 give evidence not only of heavy removal of the existing stock, but also of a failure in the entering year classes which probably originated several years previously.

In 1939, the lake was closed for the first time, and 1940 shows a remarkable improvement. A major year class (or group of year classes) apparently moved in, causing a jump over the mean in the 14- to 20-inch sizes. Because the growth of lake trout is rather slow, the size classes from 20 inches up had not recuperated. By 1942, the dominant year class, first shown in 1940, increased in length until it ranged from 16 inches to 22 inches. But there was nothing to take its place. No other year class followed, so that in 1942, the 12- to 16-inch group fell below the mean. The successful year class from 16 to 22 inches in 1942 must have been practically wiped out in that year, since the year 1944 found the trout fishing extremely poor.

Figure 4 also illustrates the trend in Little Island Lake. In 1938 there is evidence of two major year classes, one with a size range of 14 inches and less, the other at 18 to 20 inches. This latter group was removed in the year's fishing, with the result that in 1939 the only successful year classes shown above the zero line are the new ones which had grown as large as 15 inches. Given an opportunity to grow in 1940, when the lake was closed, this year class group moved into the size bracket from 18 to 25 inches. However, it appears that they were fished so intensively during the next fishing year (1943) that, if they did not actually vanish from the lake, they certainly fell far below normal in the fishery. During the same period, new major year classes suddenly appeared, measuring from 14 to 18 inches in 1943. This group was likely in the 11- to 15-inch size classes in 1942 and would have entered the fishery in that year if the lake had been open to angling. They were also heavily fished so that in 1945, although they had moved into the 22-inch to 32-inch size group, their numbers were greatly depleted.

The data for Happyisle Lake (Figure 5) cover the 10-year period with no closures. The successful year classes measuring from 18 inches to 32 inches in 1937, underwent a marked decrease in 1938, but staged a slight recovery in 1939. Presumably this 1939 increase indicates that part of the lack of success in 1938 was due to poor

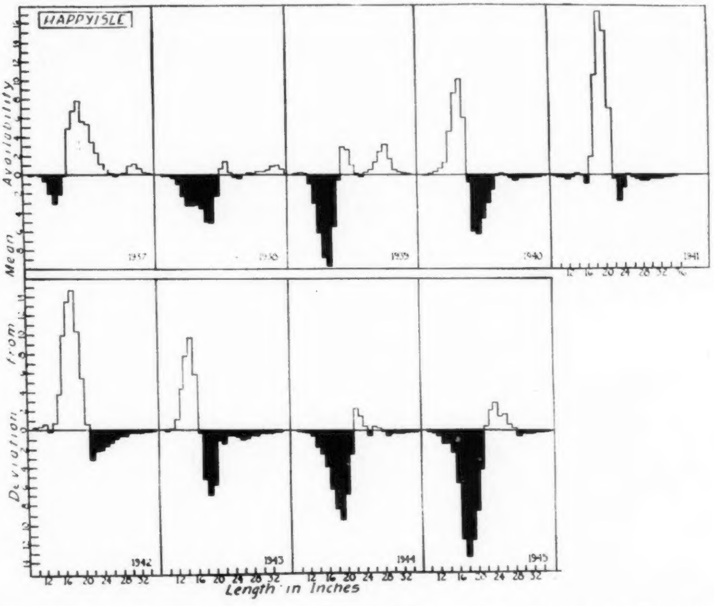

FIGURE 5.—Annual variations in the availability of lake trout in Happyisle Lake as compared with the 10-year mean, smoothed twice by threes.

fishing conditions. In 1939 the group was evidently annihilated so far as the fishery is concerned. It was followed in 1940 by the appearance of successful year classes occupying the position from 11 to 18 inches. By 1941, these lake trout had grown to a length of 22 inches, and although they did not reach beyond that length in 1942, their number was augmented by classes immediately following which were but slightly apparent in 1941. However, by 1943, they dropped below the mean to be succeeded by fish that were from 10 to 14 inches in 1942 and which had increased by 1943 to 16 inches. The histograms for 1944 and 1945 reveal a peculiarity for which the explanation possibly lies in the effect of meteorological conditions on fishing, but the effect may merely be the result of random variation of the data. Those year-class groups measuring around 19 inches to 20 inches in 1942, although apparently knocked out of the fishery in 1943, recovered sufficiently to show an increase over the average from 22 inches to 27 inches in 1944. Because there is no evidence of a new year class developing during the years 1944 and 1945, it can be concluded that a few years previous to 1944 there was a year-class failure.

There is inadequate information for Smoke Lake (Figure 6) before 1939, but the great deficiency in all sizes for both 1939 and 1940, indicates a very decisive failure of, not one, but several year classes. By 1941, the fishery recovered slightly, and new year classes moved into the sizes 10 inches to 20 inches. By 1942, the larger sizes of this latest year-class group dropped out of sight, but the sizes from 15 inches to 19 inches increased in strength. Following them came another year class shown at 11 inches. The fish measuring from 26 to 32 inches most probably represent the reappearance in the fishery

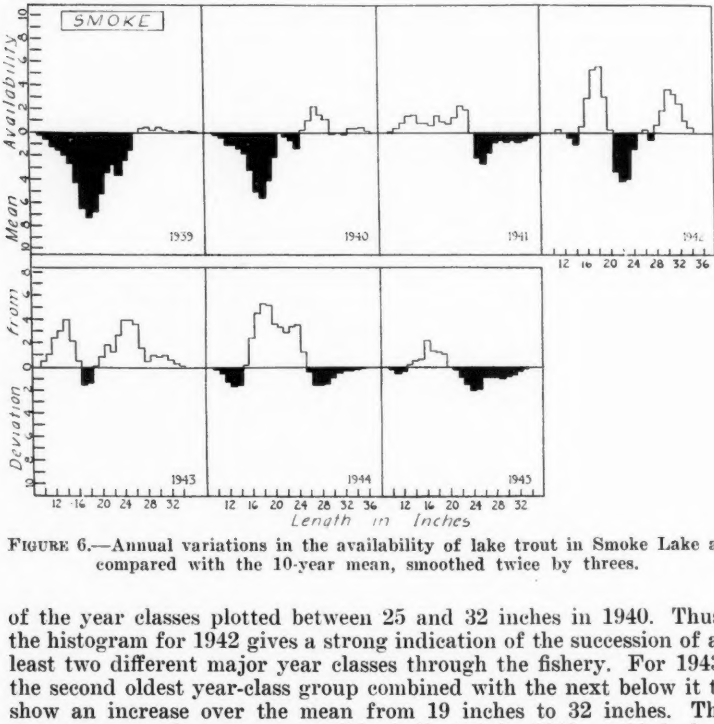

FIGURE 6.—Annual variations in the availability of lake trout in Smoke Lake as compared with the 10-year mean, smoothed twice by threes.

of the year classes plotted between 25 and 32 inches in 1940. Thus, the histogram for 1942 gives a strong indication of the succession of at least two different major year classes through the fishery. For 1943, the second oldest year-class group combined with the next below it to show an increase over the mean from 19 inches to 32 inches. The youngest year-class group possibly indicated in 1942 at 11 inches, climbed above the average between 10 and 16 inches the following year. These fish combined in 1944 with the remnants of the two older classes to cause an improvement in the sizes from 15 inches to 25 inches. But the bulk of the oldest year class had disappeared from view by 1944 and there is some evidence that the strength of the

entering year class was below normal. In the 1945 figures there is evidence of a further failure in the entering year class and those size classes which had better than average availability probably still owed their advantage to the year class entering in 1943.

In Cache Lake (Figure 7) the fisherman's chances of capturing lake trout were never better than average from 1938 to 1942, reaching their lowest point in 1940. In 1944 his chances improved immensely. Possibly the reason for the success of certain size groups in 1937 and 1944, the two good years for Cache Lake, is that in 1937 the lake was planted with mature wild lake trout. The capture of many of these fish during that season no doubt accounts for the better fishing in that year. However, about 200 were placed in the lake in the fall after fishing had stopped and it is possible that the increase in 1944 was due to the successful spawning of these planted fish, since the 7-year

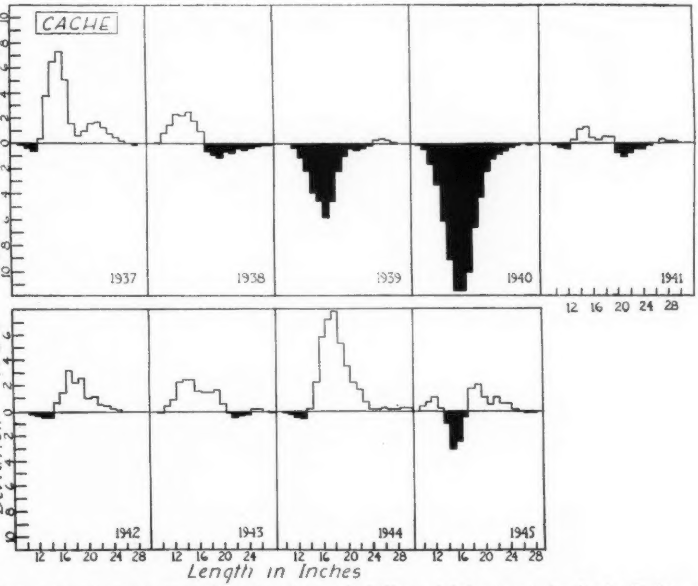

FIGURE 7.—Annual variations in the availability of lake trout in Cache Lake as compared with the 10-year mean, smoothed twice by threes.

interval is approximately the time required in Cache Lake for lake trout to reach a size large enough to take the bait.

The most accurate and detailed information derived from the creel census of the Algonquin Park lakes was obtained from the Opeongo

fishery (Figure 8). Since the main laboratory is stationed on this, the largest lake in the Park, and since the means of access to the lake are limited, close observation can be maintained there. The annual catch

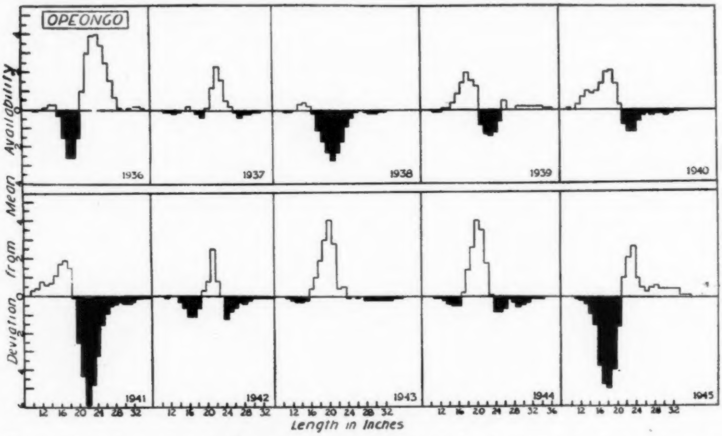

FIGURE 8.—Annual variations in the availability of lake trout in Lake Opeongo as compared with the 10-year mean, smoothed twice by threes.

from Opeongo far surpasses that of any other lake in the Park, averaging approximately 1,100 per annum. The first three years demonstrate the decline of the fishery with no new year classes following in immediate succession. The graph for 1939 reveals that the group barely visible above the average line at 15 inches in 1938 had increased in size and availability so that the fishery as a whole was better than average. In 1940 there appears to have been a further reinforcement resulting from the success of the subsequent year class. The same seems to be true in 1941. However, the intensity of the fishery during those years was sufficient to reduce these year classes soon after they had entered it. In the later war years, the fishing pressure dropped and subsequent to 1941 the latter of these major year classes show signs of progressing through the fishery. No new major year classes appear to have entered the fishery from 1941 to 1945. The progress of the year classes in the fishery from 1941 to 1945 is somewhat halting even in these smoothed curves. This irregularity probably occurred because Opeongo Lake has three distinct basins which in summer at least, contain discrete populations of lake trout. The amount of data concerning each of these populations tends to be roughly in proportion to the excellence of the fishing each population presents at any particuar time; consequently the Opeongo data are heterogeneous in spite of their relative completeness.

Every fishery described above has shown at least one major fluctuation which it seems reasonable to ascribe to a variation in the success of year classes. These examples were not chosen because they emphasize such a variation in year classes, but simply because they comprise all the fisheries for which we possess data sufficient to enable us to plot in detail the changes which have occurred in the size composition of the catches. Hence, variations in year-class strength in lake trout fisheries such as these, appear to be not only clearly defined but also practically universal.

Discussion

The most striking feature of this analysis of the lake trout fisheries is the great irregularity in the success of year classes. The data as presented in Figures 4-8 give only a qualitative appreciation of the true situation since only deviations from mean availability are shown. However, the extent of these deviations on a proportional basis can be calculated by comparing the magnitude of these absolute deviations with the appropriate mean availabilities given in Table 3. Thus, in Opeongo Lake in 1941 the drop in the size classes 20 to 32 inches. represents at least a 50-percent decrease from the mean. The rise above the mean in the same lake in that year over the range 10 to 18 inches is equivalent to an increase of about 35 percent.

The fluctuations in the early years of the census at least could not have been the result of excessive angling pressure in previous years, since the Algonquin Park highway was not opened until 1936 and many of these lakes were relatively inaccessible before that time. The fluctuations, then, as is the case with most other such variations in the strength of year classes, can be attributed to phenomena other than human interference. What these phenomena are, or in what years they operated with adverse effect on the recruitment have not yet been discovered. Fortunately substantial scale collections from a number of these lakes are on file, and thus there is the possibility of determining the age composition of the catches and of learning which were the successful and which the unsuccessful year classes.

Since the aim of fishery management is to produce consistently the most attractive angling possible, this great variation in year-class strength presents a serious problem. This is particularly so in lake trout fisheries where the attractiveness of the fishing depends on a single species and there is in general no other fish which the angler may take if the lake trout are scarce in any particular year. Presumably management practices should be sought which tend to compensate for these fluctuations in recruitment.

The discovery of this great fluctuation in year-class strength, together with the fact that lake trout grow so slowly throws light on the somewhat varying success so far as lake trout are concerned which has resulted from our program of alternate closure of small lakes in

TABLE 3.—*Mean availabilty of lake trout by size classes in various Algonquin Park lakes during the period 1936-1945.*
[The values given represent the number of fish of a given size captured per 100 boat-hours. The number of years represented in each average may be found by counting the panels in Figures 4-8.]

Name of lake	Fork length in inches																					
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Cache	0.9	2.1	6.6	9.9	14.0	15.6	13.6	7.4	4.3	1.6	1.3	0.8	0.7	0.5	0.2	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Happyisle	0.7	0.6	1.9	4.8	14.5	20.9	27.2	19.9	21.4	5.3	7.1	1.5	2.3	1.3	2.4	0.0	0.6	0.5	0.4	0.0	0.4	0.3	0.3
Little Island..	0.0	3.2	6.1	7.3	15.1	17.4	13.5	28.0	6.6	4.7	2.6	1.0	2.5	0.0	1.1	0.2	0.1	0.6	0.1	0.0	0.0	0.0	0.0
Merchant	0.0	0.3	0.4	1.5	5.2	13.5	24.0	27.8	22.2	14.7	11.0	4.5	2.9	1.1	5.5	0.5	1.2	1.2	0.8	0.7	1.7	0.2	1.8
Opeongo	0.5	0.5	1.4	2.0	4.1	5.9	9.7	14.6	19.3	17.9	14.3	8.7	5.2	2.9	2.0	0.9	0.7	0.5	0.6	0.4	0.3	0.2	0.4
Smoke	1.5	0.3	2.5	1.4	3.0	7.3	13.0	9.1	12.4	4.2	7.9	5.1	6.5	5.8	5.7	1.5	0.6	1.0	1.8	1.0	1.7	0.0	0.2

Algonquin Park. However, since this program was not initiated on a wide scale until 1939 it is perhaps still too early to come to any definite conclusions with regard to its ultimate value.

The data presented here also give a further indication of the relative sparseness of the lake trout populations in these lakes. The best figures to illustrate this point are those for Opeongo Lake. Although this lake has an area of 20.1 square miles and has a very extensive shore development, the removal of approximately 1,500 lake trout in a year appears to suppress effectively any benefit to be derived from a major year class beyond the second year after its entry. This estimate is based on the catches from 1938 to 1942. The removal of 1,500 lake trout represents one fish per eight and one-half acres.

The standard profile of availability which appears to be of some value in the classification of the Algonquin Park fisheries is probably of only local significance. However, it does seem useful in assessing management practice within this particular administrative area.

Acknowledgments

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RECOVERY OF MARKED FISH FOLLOWING A SECOND POISONING OF THE POPULATION IN FORD LAKE, MICHIGAN[1]

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ABSTRACT

In 1936, a 10.7-acre lake in Otsego County, Michigan, was treated with rotenone to eliminate a population of stunted yellow perch. An attempt to recover the entire population yielded 4,817 stunted perch, 27 trout in poor condition, and four species of minnows. The weight of what was assumed to be the total population was 516 pounds or slightly more than 50 pounds per acre. In 1937, an experimental planting of Montana grayling was made which was not successful owing to unauthorized introduction of bluegills about the same time. In 1941, 5,000 fingerling brook trout were stocked, but proved unable to compete with the rapidly increasing bluegill population and disappeared 4 years later. In 1943, walleyes were introduced in the hope of reducing the bluegill population to a point where survivors could make satisfactory growth.

In 1946, when rotenone reappeared on the civilian market, the lake was treated with poison again, and an attempt made to recover the entire population. The total weight of fish recovered was 1,293 pounds, or 111.5 pounds per acre, more than twice the poundage found in 1936; the difference perhaps can be explained by bluegills being closer to the primary food chain than yellow perch.

Of greater interest were the findings on completeness of recovery. Four and 3 days, respectively, prior to poisoning, 246 bluegills and 210 brook trout were fin-clipped and planted. Only 58.9 percent of the marked bluegills and 44.7 percent of the marked trout were recovered despite careful search. Considerable doubt is thereby cast on the prevalent practice of assuming practically complete recovery of fish populations following rotenone treatment, and figures on total fish production derived by this method.

INTRODUCTION

During the past decade, 35 lakes in Michigan have been treated with rotenone, (as available in powdered derris and cubé roots), to eliminate or reduce undesirable fish populations. Subsequent checks on these waters reveal that several of them have been repopulated with species of fish not well suited to the waters, thus defeating the purpose of the poisoning.

Ford Lake, Otsego County, Michigan, a 10.7-acre lake in the heart of the Pigeon River State Forest, is one of Michigan's potential trout lakes that had become worthless to anglers owing to the presence of a population of stunted yellow perch (*Perca flavescens*). In 1936, the Ford Lake fish population was killed by means of rotenone and

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dynamite, and an analysis of the population at that time was made (Eschmeyer, 1938).

In 1937, an experimental planting of Montana grayling (*Thymallus montanus*) was made which did not prove to be successful owing, presumably, to the unauthorized introduction of bluegills (*Lepomis macrochirus*) made at the same time or shortly following that of the grayling (Leonard, 1939 and 1940).

It was obvious by 1939 that the grayling were not able to live and grow successfully in a small lake that harbored another highly competitive species. In September 1941 a planting of 5,000 fingerling brook trout (*Salvelinus fontinalis*) was made, but they too were unable to thrive in the face of the active competition of the bluegill and were last reported from a gill net set in September 1944. No trout were taken in gill net sets in 1945.

As a result of their natural fecundity and the absence of predatory fish, the bluegills increased prodigiously in numbers and populated the lake beyond its capacity to support a growing population. In September 1943 walleyes (*Stizostedion vitreum*) were introduced as a possible means of reducing the large numbers of stunted bluegills to a point where growth would result in legal-sized fish.

With the anticipation of rotenone becoming available, plans were made to poison Ford Lake again, since conditions were favorable, to establish it as a trout lake. Such an undertaking would make possible a comparison of standing fish crops on the same lake at different times and with a different species composition. The survival of a limited number of known-age walleyes in a lake having no other predacious species and containing an ample food supply in the form of stunted bluegills could be determined. There would be an opportunity also to check on the efficiency of recovery of fish marked immediately prior to poisoning, thus shedding some light on the validity of poisoning as a means of determining total populations. With the securing of these data as a goal, Ford Lake was poisoned for the second time, by the writer and four other biologists of the Michigan Institute for Fisheries Research, on the afternoon of August 26, 1946. During the 6 days following every effort was made to recover all fish that came to the surface, or were within reach of the surface with long-handled scap nets.

Method of Applying Rotenone

The actual poisoning differed from other similar projects carried out in Michigan in the past only in the method of application of rotenone to the lake. The 300 pounds of derris (producing a concentration of 0.6 p.p.m. of derris root of 5-percent rotenone content) applied to the lake were mixed and distributed by means of a small centrifugal pump. This pump, purchased especially for the work, has a capacity of 3,000 gallons per hour and a 2-inch intake and discharge, weighs less than 100 pounds (including the $1\frac{1}{2}$-horsepower motor and

the 10-foot intake and discharge hoses), and, with the fire-hose nozzle used, throws a stream approximately 40 feet. The working unit consisted of a 55-gallon drum with the head removed placed in the front end of a rowboat and the pump located in the rear end. A 5-horsepower outboard motor was used to propel the unit. In actual operation, 5 pounds of derris powder were poured into the drum, the intake hose of the pump dropped overboard, the discharge hose directed into the drum, and the pump started. The forced stream from the hose nozzle served to fill the drum completely and thoroughly mix the derris powder in one minute. When the drum was full the end of the intake was placed in the drum, the discharge directed onto the lake, and the distribution of the mixture effected with the boat moving at slow speed. As the pump was capable of throwing a jet of water-derris mixture approximately 40 feet, it was possible to treat shoal areas that were blocked by deadheads or too shallow to permit operation of the outboard motor. Two men can operate the unit with ease and, if desired, the entire operation can be carried out without stopping either the pump or outboard motor. Eighty of the 300 pounds of derris were pumped into the deeper water of the lake with the same equipment, but using a ½-inch garden hose attached to the discharge hose of the pump and weighted sufficiently to discharge at a depth of approximately 15 feet.

Following application of the poison, the fish were collected as they came to the surface or were found in distress, taken to shore, and examined for excised fins. Measurements were taken from random samples, and weights were taken in lots of 200. The last live bluegill was seen on the morning of August 29, 2½ days after the poisoning; the last fish seen alive was a mudminnow (*Umbra limi*) on the afternoon of the same day. Both fish were in a dying condition when found. No live fish were seen after this time and no fish were taken in a 32-hour set with an experimental gill-net on August 29-30. The fish were picked up each day for the 6 days following the application of rotenone and the few fish recovered toward the last were reaching a point of disintegration that made their recovery as whole fish quite difficult. Only a very few fish were taken in the last 24 hours.

Only five species of fish were recovered at the time of the poisoning: brook trout, walleyes, bluegills, mudminnows, and one specimen of the northern mimic shiner, *Notropis volucellus*. The brook trout had been introduced 3 days prior to the poisoning and all trout recovered were from this planting. The 17 walleyes (*Stizostedion vitreum*) were the survivors of a planting of 168 made in September 1943. All had been marked by removal of the left pelvic fin when planted and all recoveries were so marked. The walleyes when planted were young-of-the-year fish having a size range 5¾-10¼ inches in total length. On recovery they ranged from 17 to 19¾ inches in total length and 1½ to 2¼ pounds in weight.

The mudminnow (*Umbra limi*) was apparently well established and reproducing in the lake.

The most important species from the standpoint of both numbers and weight was the bluegill, (*Lepomis macrochirus*).

Comparison of the 1936 and 1946 Fish Populations

The poisoning of Ford Lake was of special interest as it offered an opportunity to compare the standing fish crop at the present time with that of the same body of water 10 years earlier.

In the late summer of 1936, the fish population of Ford Lake was removed by poisoning with rotenone and by the action of a heavy charge of dynamite. At that time a complete kill was reported and all fish were accounted for by actual count or accurate estimates based on partial counts. The fish present in the lake at that time were yellow perch, brook trout, and four species of minnows. The 4,817 perch recovered, believed to be the total number in the lake, had been growing slowly; the 27 brook trout were survivors of plantings from earlier years and were not in good condition. The bulk of the minnows were *Chrosomus eos,* a species that apparently was doing well in the lake. The total fish population at that time weighed only 516 pounds, or about 50 pounds per acre.

The population as determined in the second poisoning was much different from that of the first. No yellow perch were present and the only brook trout were those stocked immediately prior to the poisoning to check on the completeness of kill and recovery. The only species of minnow common to both dates was the mudminnow, *Umbra limi.* The bluegill dominated at the time of the 1946 poisoning with a total of 37,383 specimens weighing 1,222.2 pounds. That this was a severely stunted population was indicated by the presence of only 18 legal-sized individuals (6 inches or longer) in the entire group, or one legal specimen for each 2,000 bluegills. The average length of the bluegills recovered was 3.9 inches and the average weight about one-half ounce.

Seventeen walleyes weighing 34.2 pounds, the remnants of 168 young-of-the-year planted in 1943, were recovered. Twenty-four and a half pounds of mudminnows were weighed and measured. Although the kill is believed to have been complete, it is estimated that no more than 50 percent of the dead mudminnows were recovered. The weights,

TABLE 1.—*Number and weight of fish recovered, number of fish marked, and number of fish recovered after poisoning, August 26, 1946*

Species	Total number recovered	Weight (pounds)	Number marked	Number of marked fish recovered
Bluegill	37,383	1,222.2	246	145
Walleyes	17	34.2	....	....
Brook trout	....	....	[1]210	94
Mudminnows	[2]4,293	24.5	....	....

[1]The only trout in lake were those planted from hatchery immediately before poisoning.
[2]Estimated to be less than half of mudminnows in lake.

number of marked fish, and number of marked fish recovered are shown in Table 1.

The total weight of fish recovered from Ford Lake in 1946 was 1,293 pounds, or 2.4 times the weight of fish recovered from the same lake following a complete kill 10 years previously. The reasons for this difference in weight of fish recovered are not too well understood, but perhaps the increase may be accounted for by the differences in the feeding habits of the fish making up the dominant species in the lake at the time of the poisonings. The yellow perch, dominant in the 1936 poisoning, are generally piscivorous in their feeding habits, whereas the bluegill, the major component in the second poisoning, is largely dependent upon invertebrates for food, and is thus closer to the primary food chain.

Recovery of Marked Fish

Shortly before application of the rotenone, 456 marked fish were introduced into the lake as a means of checking the efficiency of recovering the total fish population following poisoning. Four days prior to poisoning, 240 bluegills averaging 4.1 inches, total length, were caught by hook and line, their dorsal fins removed, and the fish released. In addition, the anal fins of six bluegills of less than 3.5 inches, total length, were clipped and the fish released. Three days prior to poisoning, 210 brook trout, ranging from 4 to 11 inches in total length, obtained from a nearby State Fish Hatchery, were marked by removal of their dorsal fin and placed in the lake. These brook trout were seen in all areas of the lake the morning prior to the poisoning.

A recovery of 145 of the 246 marked bluegills was made in the 6-day period following the treatment of the lake with rotenone. They constituted 58.9 percent of all marked bluegills presumed to be alive in the lake at the time the rotenone was applied. Ninety-four (44.7 percent) of the 210 trout were recovered. The percentage recovery of all groups of fish was lower than anticipated and poses a question as to the validity of population estimates derived from the pick-up of fish following poisoning.

Checks on the recovery of marked fish present in a lake have been made in three previous poisonings in Michigan. Following the poisoning of Third Sister Lake (Ball, 1944) 23.4 percent of the 1,395 fish that had been marked by tagging or fin clipping were recovered. These fish had been in the lake from 9 to 22 months prior to their removal and natural mortality had undoubtedly reduced the number of marked fish. Since no estimate of the natural mortality can be given, these figures cannot be considered as indicative of the proportion of the total population recovered. The fish marked were bluegills, largemouth bass, bullheads, and pumpkinseed sunfish. More bluegills were marked than all other species combined.

Carbine (unpublished) found that 13.7 percent of 699 marked fish (10 species) were recovered following removal of the fish population of Deep Lake, Michigan. These marked fish also had been in the lake for varying periods of time up to 2 years. Krumholz (1940) reported on a population study of Twin Lake, Michigan. In this study, a population estimate was made based on the recovery by nets from known numbers of marked fish. The validity of calculation was then checked by poisoning, and 86 percent of all marked fish assumed to be alive in the lake were recovered. The population of this lake was of the bass-bluegill type.

The fate of the marked fish and the portion of the entire population they represented in Ford Lake can be only a matter of conjecture at the present. The weed beds of the bottom were visible through the clear water to a depth of 18 feet, which was the lower limit of the vegetation. Once the power of locomotion was lost as a result of the effect of the rotenone, a majority of the fish sank to the bottom where many could be seen in the dense, compact mat of *Chara* carpeting the lake. By the end of the fourth day all fish that had been on the bottom within the range of visibility had floated to the surface. There is the possibility that many of them, after becoming affected by the rotenone, had buried themselves in the *Chara* mat as a result of the uncontrolled, erratic dashing about that is a characteristic reaction to the poison. Many fish that were partially buried in this manner were seen to rise to the surface when bloated, often with enough force to bring strands of *Chara* and other algal growth with them. Still another possibility, and perhaps the most likely one, is that they sank into the deep water and did not come the surface before they disintegrated. At the time of poisoning the lower waters of Ford Lake were devoid of oxygen, the carbon-dioxide content of the water was 12 p.p.m., and the pH 6.6. The bottom was covered with a layer of pulpy and fibrous peat.

The results just described indicate strongly the need for further investigation into the fate of that portion of the fish population of a lake that does not float to the surface in the few days following poisoning with rotenone. If the 54 percent of the marked fish recovered in Ford Lake signified that only that proportion of the entire population was recovered, the estimates of total fish production of inland lakes, which have been made largely on the results of poisoning lake populations, will have to be revised sharply upwards. This observation assumes, of course, that the percentage recovery in other lakes is comparable to that in Ford Lake. This assumption may not be tenable but only a thorough check on future poisonings will clarify that point.

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RELATION OF TEMPERATURE TO SURVIVAL AND INCUBATION OF THE EGGS OF SMALLMOUTH BASS (*MICROPTERUS DOLOMIEU*)

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ABSTRACT

Field observations indicated considerable loss of eggs of smallmouth bass and a high incidence of fungus infection in the nests in Cayuga Lake, New York, and tributaries. To investigate the possible effect of temperature changes on embryo survival, several tests were run using constant-temperature facilities at the Cornell University Insectary. In 1945, two trials were run raising the temperature of developing ova from 53° to 77° F., and no eggs were killed. During 1946, eggs developing at 65° F. were transferred at 0, 1, 2, 3 and 4 days following fertilization to 50° and 75° F. None of the eggs was adversely affected. The temperature changes took place within one-half hour. The mean incubation period was determined to vary from about 2¼ days at a constant temperature of 75° F. to nearly 10 days at 55° F. The observations presented lead to the conclusion that temperature changes in the ranges indicated are not directly responsible for the death of smallmouth bass embryos.

INTRODUCTION

Since 1941 the Laboratory of Limnology and Fisheries has been engaged in a long-term study of the smallmouth bass in Cayuga Lake. Part of the investigation involved a detailed study of the success of natural reproduction during the course of which it early became apparent that a large number of naturally deposited ova died or were lost when fungus invaded the nest. Whereas most of the natural nests exhibited fungus infection to a limited degree, in others fungus rapidly enveloped the entire nest resulting in a total loss of the ova. This condition has been noted both in smallmouth bass nesting directly in Cayuga Lake and in the lower reaches of one of the larger tributaries, Taughannock Creek.

One may infer from the literature that fluctuations of water temperature are directly responsible for the death of bass eggs, or they may be indirectly responsible by causing the male to desert the nest, after which many of the eggs die owing to the lack of parental care (Reighard, 1905; Meehan, 1911; Beeman, 1924; Tester, 1931; N. Y. Cons. Dept., 1934; Rawson, 1938 and 1945; Surber 1943). The presence of dead eggs presumably opens the way for fungus infection which may eventually envelope many living eggs.

During the springs of 1945 and 1946 two experiments were run to obtain pertinent information on the sensitivity of the smallmouth bass embryo to temperature changes. It was also possible to obtain reasonably accurate data on the incubation period of the eggs at various temperatures; the results of these observations are also reported.

Material and Methods

The constant-temperature facilities of the Insectary of the Department of Entomology and Limnology were made available for these experiments. The equipment consisted of a battery of 12 insulated boxes equipped with Minneapolis-Honeywell "Temperature Controllers." These boxes in normal operation hold the temperature to within a fluctuation of about $\pm$ 1° F. of the thermostat setting.

Eggs were secured at the Cornell Experimental Fish Hatchery from wild breeders taken from Cayuga Lake. The general procedure consisted of carefully watching a newly cleaned nesting box so that the time of spawning and fertilization was approximately known. Rocks from the nest were then removed and the eggs brushed off into a pan.

Fingerbowls, 10 centimeters in diameter, containing about 200 cubic centimeters of hatchery (creek) water were used as containers in which the eggs were incubated. The water in each bowl was changed at least once a day and two or three times daily for eggs held at temperatures above 65° F. Dead eggs, when present, were decanted off at this time. During the 1946 trials the fingerbowls in the boxes above 65° F., were covered to eliminate the slight lowering of the temperature due to evaporation. No eggs were incubated successfully above 80°. It was not apparent whether the temperature or the rapid fouling of the water caused the mortality. No attempt was made to hold eggs below 50° F.

Quite evidently, embryos of smallmouth bass are relatively hardy through all stages of development as the necessary handling produced no excessive mortality.

Effect of Temperature Changes

On June 3, 1945, eggs from a nest fertilized May 27 were transferred to the following temperatures: 55 (control), 59, 68, 71, and 79° F. The pond water at the time of transfer was 53° F. The adjustment in water temperature in the bowls to that of the box took up to about one-half hour; hence the change may be considered rather abrupt compared with conditions which one might encounter in nature.

The eggs were incubated successfully at each temperature with no unusual mortality. Those raised to the higher temperatures hatched within a few hours of the transfer. The healthy and very active fry produced were carried through several days before the trial was terminated. A second trial was run on eggs from the same nest just prior to their hatching with identical results. The conclusion follows that a temperature rise of up to 24° F. (allowing -2° for the effects of evaporation) was not fatal to the eggs of smallmouth bass which were about to hatch.

During 1946 a different procedure was followed. Twelve lots of newly fertilized eggs were counted out. All but 2 of these lots were placed in the 65° F. box (pond water at time of transfer, 66° F.). Of the 2 bowls not so treated, one was transferred immediately to 50°, the other to 75° F. Then on each successive day of incubation, a similar procedure was followed, *i.e.*, a bowl was removed from the 65° box and transferred to 50°, another to 75° F. The transfer on the fourth day was just prior to hatching. This gave 5 changes to a low and a high temperature at 0, 1, 2, 3, and 4 days of incubation, leaving 2 bowls for controls at 65° F.

The eggs in all of the bowls developed without appreciable mortality and produced healthy living fry, except in the transfers to 75° F. on days 1 and 2. Here the fry hatched but the water became fouled through lack of adequate care and the fry quickly died.

From the above observations it would appear that temperature changes from 50° to 75° F. are of no direct consequence in determining the survival of smallmouth bass eggs.

Field observations are also in agreement with the foregoing conclusions. For example, in 1945 eight early nests in Taughannock Creek were largely deserted by the males when the temperatures fell from 56° to slightly below 50°, but the eggs were not killed. During 1946 thermograph records were available during the period of spawning and nesting. The mean daily temperature fluctuation during 24 days of June was 10.5 $\pm$ 3.5° F. The temperatures extremes during the same period were 52° and 80° F. These readings were made in the main channel of the stream; backwaters were known to exhibit extremes of several degrees greater than this. Wide fluctuations are evidently to be expected during the spawning season, and many eggs deposited throughout the season developed normally.

Incubation Period

Data on incubation periods at the several temperatures are available for the 1945 and 1946 seasons. Although these periods are recorded to the nearest hour, no implication of such accuracy is intended. In the first place, four or five hours usually had elapsed between the time of the initial spawning and the time the transfers could be effected. Secondy, the mean incubation time (the time required for approximately 50 percent of the eggs to hatch) frequently had to be interpolated inasmuch as observations were made only at about 4-hour intervals between 8 a.m. and 8 p.m. This was particularly true at the higher temperatures, at which nearly all of the eggs hatched simultaneously. Furthermore, in 1945 evaporation contributed a slight negative deviation from the thermostat setting. The discrepancy was determined to be about 2° at 78° F., but was considerably less at the other temperatures; except in the instance mentioned no attempt at a correction has been made. However, the results for the 2 years'

observations are in reasonable agreement whatever the variability contributed by the conditions enumerated above.

The mean incubation periods are given below, those for 1945 being marked with an asterisk:

Temperature (°F.)	77*	75	71*	70	67*	65	60	59*	55*	55
Incubation period (hours)	52	54	70	78	90	98	150	167	238	234

Thus the incubation period at a constant temperature of 75° is about $2\frac{1}{4}$ days, whereas at 55° it is between $9\frac{1}{2}$ and 10 days.

TABLE 1.—*Incubation period of the eggs of smallmouth bass as reported in the literature*

Source	Incubation period	Temperature
Manual of Fish Culture, U. S. Comm. of Fisheries, 1900 (referring to "black bass").	70 hours to 4 days	63° F. "or somewhat over"
Beeman, 1924.	7 days 14 days 21 days	70+° F. 64° to 70° F. 59° to 64° F.
Embody (unpublished notes).	4 days 10 to 12 days	74° F. 60° F.
Langlois, 1931.	7 to 16 days	Minimum of 60° F. to maximum of 80° F.
Rawson, 1938.	4 days	65° to 70° F.

Incubation periods reported in the literature which have come to the writer's attention are given in Table 1. The discrepancy between these data and those currently presented is no doubt due in large part to nocturnal-diurnal temperature fluctuations in natural waters.

Possible Causes of Egg Loss

The foregoing observations appear to indicate that temperature fluctuations within the range indicated are at least not directly responsible for the death of the embryo, but they offer little to explain heavy egg loss and fungus infection in many nests. Further discussion of the matter is contemplated for a future report from investigations now under way. For the present, suffice it to say that the presence or absence of the male bass appears to bear little relation to the numbers of dead eggs, the degree of fungus infestation, or to the amount of silt deposited on the nest. Nests lost through fungus may occur singly or in localized groups, but in either situation the development of the fungus is most explosive, enveloping the entire nest within a day or so. The possibility of infertility of either of the sexes or of the effect of temperature on the efficiency of fertilization has been considered, but has not been investigated as yet.

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EFFECTS OF AN AERIAL APPLICATION OF WETTABLE DDT ON FISH AND FISH-FOOD ORGANISMS IN BACK CREEK, WEST VIRGINIA[1]

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ABSTRACT

A 0.9-mile section of Back Creek at Glengary, West Virginia, was sprayed by airplane with wettable DDT at a rate of 1 pound per acre. Analysis of the deposit showed that 0.39 pound of DDT per acre was actually laid down on the stream surface. Quantitative bottom samples taken of the insect fauna in the riffles, before and after spraying, showed a survival of about 30 percent at the lower stations.

Samples of drifting insects collected before and after spraying showed an immediate heavy loss of caddisfly larvae and mayfly nymphs. Caddisfly larvae were killed first. The largest number of insects drifting downstream occurred within the first 3 hours after spraying. At the end of 9 hours the number of drifting insects was reduced almost to normal. The wettable-DDT spray did not affect surface insects, such as water striders and whirligig beetles, to any important extent. Since it is known that streams can recover from catastrophic losses of bottom insects as a result of floods, it is believed that no permanent harm is caused by a single application of DDT such as would ordinarily be used in the control of forest insects.

Although the sprayed section of the stream contained large numbers of bluntnose minnows, spotfin shiners, silverling minnows, and fallfish, these species were little affected by the DDT application. Only 61 native fishes were found dead. One-half of these were smallmouth black bass, whereas most of the remainder were stoneroller and common suckers. Practically all the fish affected were hatched during the 1946 season.

Live-boxes stocked with warm-water fishes were placed at intervals above, below, and within the sprayed section. Of 374 fish exposed to DDT in these boxes, 10.7 percent were lost from all causes, including DDT.

Wettable DDT applied at 1 pound per acre apparently is not so toxic to fish and fish-food organisms as the same amount of DDT applied in an oil spray.

INTRODUCTION

Field studies initiated by the Bureau of Entomology and Plant Quarantine in 1944 showed the feasibility of applying DDT by airplane for the control of several forest-insect pests. During the next 2 years practical tests were made on large insect-infested forest areas to study operational problems, dosages, and the effects of this poison

[1]Presented at the Seventy-sixth Annual Meeting.

on insects, fish, and wildlife (Craighead and Brown, 1945 and 1946). The Fish and Wildlife Service since early in 1945 has cooperated with the Bureau of Entomology and Plant Quarantine in studying the effects of this poison on fish and other animals; the general results of the first year's work have been published (Cottam and Higgins. 1946). Preliminary information on the effects of DDT on aquatic insects in ponds and streams has been reported (Hoffmann, *et al.*, 1946). Pond experiments conducted in 1945 (Surber, 1946) indicated that DDT was less toxic to fish when used as a suspension in water than when it was used in oil solution or emulsion sprays. Additional field and laboratory experiments were therefore conducted in 1946, primarily to determine the effects of wettable-DDT sprays and the feeding of DDT-sprayed (with suspension and oil solutions) insects on several species of warm- and cold-water fishes. Tests to date show that DDT suspensions cause the least damage to fish and fish food. The efficacy of using them for the control of forest pests, however, has not been thoroughly investigated.

Description of Stream

A 0.9-mile section of Back Creek, a warm-water bass stream located near Glengary, West Virginia, was sprayed from an airplane. The average width of the stream at this place is 72 feet, the average depth 21 inches, and the stream flow about 21 cubic feet per second. The water is soft (methyl-orange alkalinity, 51 p.p.m.). Back Creek is generally sluggish in this section, with long pools separated by short gravel and rubble riffles. The gradient of the stream in this area is about 0.45 foot per mile. The occurrence of few cultivated fields in the valley accounts for the usual clearness of the water. The water-willow, *Dianthera americana,* is a common emergent weed in this section of the stream. It occurs on all gravel bars and constitutes an important shelter for young fish.

Submerged plants were relatively scarce. A few beds of *Chara, Anacharis,* and *Potamogeton crispus* were present in the pools in places where there were accumulations of mud and silt. The stream was bordered by steep banks which rose almost vertically 6 to 15 feet. Tall trees 40 to 50 feet in height, some of which were a foot or more in diameter, were present upon the banks. The predominating trees were sycamore, silver maple, willow, ash, and elm. Willow and sycamore seedlings were abundant on flat shores adjacent to the stream. There were a few prominent riffle areas in this length of the stream. Three pools in the area were several hundred feet long and had a maximum depth of about 8 to 10 feet.

The stream was examined before the spraying to determine what species of fish were present, and which occurred in largest numbers. The most important minnow species were the bluntnose minnow (*Hyborhynchus notatus*), the spotfin shiner (*Notropis spilopterus*),

the silverling minnow (*Notropis amoenus*), and the fallfish (*Leucosomus corporalis*).

During the course of the observations on fish it was noted that large schools of bluntnose minnows and silverling minnows were found at the same points on each visit. There were schools of bluntnose minnows containing thousands of individuals located at specific points. Other abundant species were the stoneroller sucker (*Hypentelium nigricans*) and the common sucker (*Catostomus commersonnii*). These were mostly young fish about 2 inches long.

Adult red-bellied sunfish (*Lepomis auritus*) about 4 to 7 inches long were common in the long pools. Smallmouth black bass (*Micropterus dolomieu*), ranging from 8 to 15 inches in length, although the most sought-after gamefish in Back Creek, were relatively scarce. Young smallmouth bass of the year could be found with relative ease along the edge of the gravel bars in the quieter reaches. Less common species were the pickerel (*Esox niger*), the chub sucker (*Erimyzon oblongus*), and the blacknose dace (*Rhinichthys atronasus*).

Methods

Open live-boxes (60 by 26 by 26 inches) were placed above, below, and within the sprayed section at five points. These live-boxes were stocked with largemouth black bass (*Huro salmoides*), bluegill sunfish (*Lepomis macrochrus*), golden shiners (*Notemigonus crysoleucas*), and goldfish (*Carassius auratus*). During the experiment the fish were fed bread. Only bluegill sunfish, golden shiners, and goldfish took the bread readily.

A seine (150 by 6 feet) of quarter-inch mesh was stretched across the stream 1 mile below the Glengary Bridge to intercept dead or dying fish that might be drifting downstream.

A week before the spraying, five quantitative samples of bottom insects were taken with a stream square-foot sampler (Hess, 1941) at each of five stations designated as follows: A, 0.5 mile above sprayed section on the same stream (control); B, Glengary Bridge, head of spray run; C, 0.5 mile below head of spray run; D, 0.8 mile below; and E, 2.0 miles below. Figure 1 illustrates Station C.

Similar quantitative samples were taken at these stations a week after spraying. These samples were taken in riffles where the water was about 7 inches deep and where the bottom was mostly gravel with some rubble. The percentage survival at Stations B to D was computed by the formula $100 \frac{A_2/A_1}{C_2/C_1}$ where A_2 is the post treatment population in the sprayed area, A_1 the pre-treatment population in the sprayed area, C_2 the post-treatment population in the control area, and C_1 the pre-treatment population in the control area.

To determine the abundance of drifting insects before and after spraying, samples were collected at the 0.8-mile station by holding a

square-foot stream sampler (Surber, 1937) facing the current 3 inches below the surface and also upon the bottom of the stream, without disturbance of the latter, at intervals throughout the day. The specimens were washed off the net into pans, strained, and preserved in 3-percent formalin solution.

FIGURE 1.—Back Creek at Station C, 0.5 mile below the Glengary Bridge.

Prior to the spraying, stations for measuring the amount of DDT actually deposited were established at 0.1-mile intervals. At each station wooden stakes were driven into the creek bed at 15-foot intervals across the stream. These stakes supported 1-foot-square pieces of plywood for use in holding glass plates and large filter papers for the collection of DDT deposits.

A 50-percent wettable DDT powder, consisting of 50 percent each of DDT and an inert material containing a wetting agent, was applied as a suspension at the rate of 1 pound of DDT per acre. The spraying was done with an N3N biplane equipped with multiple nozzles.

The spraying was carried out under ideal weather conditions at 6:40 a.m. on July 24, 1946, at which time the water temperature was 73° F. There was very little wind movement, and a uniform deposit of the DDT suspension, which contained methylene blue as a tracer, was noted on the filter paper, the glass slides, and on the foliage at

all stations. An analysis of the DDT deposit obtained on the glass plates, based on the total chlorine method, indicated an average of 0.39 pound per acre (range 0.0 to 1.1 pound). Laboratory tests with the wettable DDT used for the stream treatment showed that mosquitoes, *Aedes aegypti* (L.), were killed by a concentration of about 0.005 p.p.m. of DDT. Tests with Back Creek water collected at Station D at intervals after the spraying showed that the water was no longer toxic to these mosquitoes after 9 hours.

Effects on Invertebrates

General observations indicated that the spraying did not materially reduce surface and free-swimming Coleoptera and Hemiptera. Late in the afternoon on the day of the spraying, schools of adult gyrinids and gerrids and numbers of hydrophilids were showing normal activity. These insects were not greatly affected, probably because the wettable material was not widely dispersed on the surface film. Affected caddisfly larvae which had been attached to rocks in this stream were drifting at the surface within 10 minutes after spraying; they fell easy prey to spotfin shiners and silverling minnows, which gorged upon them.

The large number of drifting insects (Table 1) taken shortly after the spraying, as compared with the number taken in an untreated portion of the same stream, showed a rapid paralyzing effect of the DDT on aquatic forms. Of 5,553 insects captured in the samples taken after the spraying, 90 percent were taken within the first 3 hours, and 59 percent of these in the second and third hours. Caddisfly larvae, principally *Chimarra obscura* (Walk.) and *C. socia* Hag., were very susceptible to the spray, and large numbers were collected in the first half-hour, whereas several mayflies and certain beetles were not seriously affected until 1 to 3 hours after spray application (Table 1). Table 2, which shows the effect of the DDT application upon the bottom forms, reveals good survival (67 percent) at Station B. The two stations below it show poorer survival (26 and 33 percent), presumably because of greater dosage through accumulative effects downstream. One of the poorest survivals (29 percent) occurred at Station E, 1.1 miles below the sprayed area. Earlier work (Hoffmann *et al.*, 1946) with a DDT-oil spray indicated a 10-percent survival of the bottom animals in the lower part of a treated section of a stream. In spite of this, the stream became repopulated with an abundance of bottom animals within a year.

An estimate of the effect of the DDT spray on some of the more abundant forms in Back Creek is indicated in Table 2. Many of the forms that were nearly exterminated or greatly reduced in numbers were taken abundantly in the drift samples. The caddisflies in the lower sprayed stations were almost exterminated. Their susceptibility

TABLE 1.—*Number of insects captured in a 1-square-foot net held against the current for 5 minutes, with net bottom 3 inches below the water surface (S) and on the bottom (B) of Back Creek, before and after spraying with wettable DDT.*

Kind of insect[1]	In check area				In sprayed area after																	
	½ hour before spray[2]		4 hours after spray		½ hour		1 hour		2 hours		3 hours		5 hours		7 hours		9 hours		13 hours		25 hours	
	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
MEGALOPTERA																						
Nigronia serricornis	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....
EPHEMEROPTERA																						
Baetis spp.	1	....	....	....	....	....	10	37	18	105	13	96	3	9	1	2	....	1	....	....	....	....
Caenis sp.	....	....	....	....	....	....	....	....	1	....	6	....	....	....	....	....	....	....	....	....	....	....
Ephemerella sp.	....	....	....	....	....	7	4	16	5	12	....	52	6	7	....	10	....	1	....	9	....	....
Heptagenia maculipennis	....	....	2	....	....	1	18	129	34	147	23	89	3	3	....	2	....	....	....	....	....	....
Iron rubidus	....	....	....	....	....	....	2	8	3	5	4	....	....	3	....	....	....	....	....	....	....	....
Isonychia albomanicata	....	....	....	....	....	6	32	171	14	23	9	5	....	....	....	....	....	....	....	....	....	....
Pseudocloeon carolina	....	....	....	....	....	1	3	28	10	29	2	10	2	2	....	....	....	1	1	....	....	....
Stenonema sp. A.	....	....	....	....	....	....	....	9	....	13	....	119	16	....	....	....	....	....	....	....	....	....
Stenonema near ***fuscum***	....	....	....	....	....	....	....	....	**9**	**34**	**23**	**114**	**3**	**12**	....	**2**	....	....	....	....	....	....
Stenonema rubrum	....	....	....	....	....	....	....	1	6	15	1	12	....	1	....	....	....	....	....	....	....	....
Stenonema spp.	....	....	....	....	....	....	....	5	16	28	35	67	1	5	....	1	....	....	....	....	....	....
Other Ephemeroptera	1	....	2	....	....	4	19	363	183	535	108	743	62	187	16	30	4	12	....	5	1	....
ODONATA	....	....	....	1	....	1	....	....	....	2	....	....	....	2	....	3	....	....	....	....	....	....
PLECOPTERA																						
Acroneuria internata	....	....	....	....	....	....	....	....	....	3	3	7	1	1	....	2	....	....	....	2	....	....
Neoperla clymene	....	....	....	....	....	....	....	....	....	1	2	....	1	2	....	1	....	1	....	....	....	....
HEMIPTERA																						
Gerridae	....	....	....	....	9	....	2	....	2	....	1	....	....	....	....	....	....	....	....	....	....	....
COLEOPTERA																						
Berosus peregrinus	....	....	....	....	....	....	5	....	3	2	15	....	3	....	....	....	....	....	....	....	....	....
Dineutes sp., larva	....	....	....	....	....	....	....	1	....	1	....	5	....	....	....	....	....	....	....	....	....	....
Gyrinus sp., larva	....	....	....	....	1	....	....	....	1	....	1	....	....	....	....	....	....	....	....	....	....	....
Heterlimnius trivittatus	....	1	1	....	....	3	5	58	6	35	1	13	1	....	1	1	....	1	....	....	....	....
Microcylloepus pusillus	....	....	**1**	....	....	**1**	**4**	**35**	**6**	**30**	**3**	**11**	**1**	**4**	**1**	**3**	....	....	....	....	....	....
Psephenus herricki, larva	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....
Simsonia sp., larva	....	....	....	....	....	....	....	....	....	1	....	1	1	....	....	2	1	....	....	....	....	....
Simsonia near *vittata*	....	....	....	....	....	2	2	6	3	4	3	6	....	4	1	4	1	2	....	....	....	....
Stenelmis near *mera*	....	1	....	....	....	2	4	20	4	12	....	11	....	4	....	1	....	2	....	2	....	1
Stenelmis spp., larva	....	....	....	....	....	....	....	1	2	10	....	10	1	6	....	6	....	1	....	....	....	1
Other Coleoptera	....	....	....	....	....	....	....	....	....	2	....	1	....	3	5	1	3	....	1	....	1	....
TRICHOPTERA																						
Chimarra obscura	....	....	....	....	235	108	8	8	12	12	12	15	....	1	....	1	....	1	....	....	....	....
Chimarra socia	....	....	1	....	89	79	11	7	8	4	2	2	....	1	1	2	....	....	....	....	....	....
Cheumatopsyche spp.	....	....	....	....	1	1	3	32	14	31	9	31	....	3	....	1	....	4	....	3	....	....
Hydropsyche spp.	....	....	....	....	1	....	2	....	....	3	3	13	1	1	1	4	....	....	....	....	....	....
Macronemum zebratum	....	....	....	....	3	34	2	12	1	2	....	6	2	....	1	1	....	....	....	....	....	....
Polycentropus sp.	....	....	....	....	....	1	....	....	....	7	2	33	3	....	3	6	....	1	....	....	....	....
Other Trichoptera	....	....	....	....	....	....	....	14	....	21	....	30	....	....	....	3	....	....	....	2	....	....
DIPTERA																						
Chironomidae	....	....	....	....	....	2	....	10	....	....	....	8	2	8	1	....	....	2	....	....	....	....
Total	2	2	7	1	339	253	136	971	361	1,129	281	1,510	113	269	32	90	10	30	2	23	2	2
Percentage of total specimens (5,553) collected after spray					11.0		20.0		26.8		32.2		6.9		2.0		0.7		0.4		[3]0.0	

[1]Coleopterous forms are adults except where noted; all other forms are larvae or nymphs
[2]Actually taken in sprayed area
[3]Less than 0.05

TABLE 2.—*Average number of invertebrates per square foot in Back Creek.*
[Based on 5-square-foot bottom samples taken 1 week before and after spraying the stream with wettable DDT by airplane]

Kind of invertebrate[1]	Station A		Station B		Station C		Station D		Station E		Effect of treatment[2]
	Pre-treat-ment	Post-treat-ment	Pre-treat-ment	Post-treat-ment	Pre-treat-ment	Post-treat-ment	Pre-treat-ment	Post-treat-ment	Pre-treat-ment	Post-treat-ment	
ANNELIDA											
Oligochaeta	2.0	0.4	......	......	0.4	......	......	......	0.6	1.4	....
MEGALOPTERA											
Nigronia serricornis	1.2	3.2	0.6	1.2	0.6	0.2	0.8	0.4	......	1.0	A
Corydalus cornutus	2.2	4.0	0.4	4.2	1.0	1.4	0.8	1.4	......	0.8	A
EPHEMEROPTERA											
Baetis spp.	3.6	3.4	1.8	0.8	2.0	......	2.2	......	5.6	......	E
Heptagenia maculipennis	2.8	1.8	6.2	1.0	5.8	......	7.6	......	2.6	......	E
Iron rubidus	1.2	....	0.2	......	1.0	......	0.2	......	......	......	....
Isonychia albomanicata	7.2	17.2	0.8	2.4	5.2	......	2.8	......	11.4	......	E
Pseudocloeon carolina	0.8	1.0	0.2	......	1.4	......	1.8	......	1.0	......	C?
Stenonema near *fuscum*	6.0	1.8	6.8	0.2	14.2	......	3.6	......	2.0	......	E
Stenonema rubrum	5.8	9.2	0.4	2.6	4.8	......	5.2	......	......	......	E
Stenonema spp.	0.4	4.4	......	1.0	......	......	4.0	......	6.6	0.2	....
Other Ephemeroptera	....	4.6	0.2	3.0	0.8	0.2	2.2	0.2	7.6	0.4	....
ODONATA	....	....	......	0.2	......	0.2	......	......	0.4	......	....
PLECOPTERA											
Acroneuria internata	5.6	4.0	3.0	2.0	4.8	1.4	2.6	0.6	1.2	0.4	B
Acroneuria sp.	....	....	......	......	......	......	......	......	0.8	0.4	....
Neoperla clymene	2.6	0.4	1.0	1.6	1.2	5.2	4.2	2.6	4.6	1.0	B?
Neophasganophora capitata	1.4	1.6	1.4	3.0	2.2	1.2	1.2	0.4	......	0.2	B?
COLEOPTERA											
Berosus peregrinus	....	....	......	0.2	......	......	......	......	......	0.4	....
Gyrinus sp.	....	0.2	......	......	0.6	......	0.4	......	0.6	......	....
Heterlimnius trivittatus	2.8	6.4	6.2	3.4	5.2	0.2	2.6	......	2.4	0.8	B
Microcylloepus pusillus	1.8	10.2	5.2	2.4	3.0	......	4.0	......	1.4	......	B
Psephenus herricki	....	0.2	......	......	0.2	0.2	......	......	0.2	......	....
Psephenus herricki, larva	0.4	0.4	1.2	......	0.8	0.8	1.4	0.2	0.4	0.2	....
Simsonia sp., larva	3.6	2.8	4.8	2.8	5.2	2.8	3.4	1.8	0.8	0.2	B?
Simsonia near *vittata*	....	....	0.4	......	0.6	......	0.6	......	0.6	......	....
Stenelmis near *mera*	4.4	10.8	9.0	4.2	10.8	3.6	6.8	1.4	2.2	2.4	B
Stenelmis spp., larva	6.6	9.6	6.2	6.6	15.2	17.8	16.4	11.8	3.8	2.8	A
TRICHOPTERA											
Chimarra obscura	14.0	21.2	4.6	1.8	28.0	0.8	17.6	1.0	1.6	0.6	D
Chimarra obscura, pupa	2.2	0.4	0.4	0.8	3.4	3.0	1.8	0.6	0.4	0.6	A
Chimarra socia	9.0	10.8	2.0	2.2	9.2	......	13.2	......	0.8	......	E
Cheumatopsyche spp.	10.4	8.4	4.8	0.2	18.6	......	10.2	0.2	7.2	......	D
Hydropsyche sp.	9.4	3.6	1.6	1.4	5.8	0.4	4.6	......	0.4	0.2	D
Macronemum zebratum	0.6	0.8	0.2	0.8	4.2	......	4.0	0.2	0.6	......	....
Other Trichoptera	0.6	0.4	0.6	0.4	0.6	......	1.4	......	1.8	0.6	....
DIPTERA											
Chironomidae	2.0	0.4	0.2	0.8	0.4	......	2.2	0.6	2.4	......	B?
Hemerodromia sp.	1.4	0.4	1.4	0.6	1.6	0.4	1.0	0.2	0.4	......	....
Other Diptera	1.4	0.8	0.4	1.6	......	1.4	0.6	1.0	0.4	0.2	....
MOLLUSCA											
Nitocris carinatus	13.2	11.8	9.4	14.2	5.0	12.0	21.6	37.4	5.6	13.0	A
Sphaerium stamineum	1.8	1.6	......	0.2	......	......	......	......	......	......	....
Total	128.4	158.2	81.6	67.8	163.8	53.2	153.0	62.0	78.4	27.8	
Percentage survival	123		67		26		33		29		

is apparently due in part to the nets that they form to strain out their food. A part of the *Chimarra obscura* population, however, had pupated and escaped any deleterious effect of the spray. The mayflies, which are vegetarians, were very susceptible to the DDT spray and were practically eliminated from the lower part of the sprayed area. Most of the large, carnivorous stonefly nymphs were not seriously affected. Elmid beetles were reduced in numbers, but their larvae were probably unaffected. The megalopterons taken in this stream are well known predators and were not affected by the DDT spray.

A snail, *Nitocris carinatus* Bruguière, that occurred abundantly on the bedrock in this stream, was not affected by the spraying. This fact was shown, not only by samples taken with the stream sampler (Table 2), but by counts taken in the middle of the sprayed area. The number of snails per square foot ranged from 21 to 160. There was no appreciable difference in six counts taken before spraying and six counts after spraying.

Effects on Vertebrates

The losses of native fishes which were observed in Back Creek following the spraying are recorded in Table 3. In spite of the abundance of bluntnose minnows, spotfin shiners, and silverling minnows, none of these species were found dead until 2 days after spraying. These results were very different from the results in the Patuxent River near Bowie, Maryland, where 2 pounds of DDT per acre in an oil spray caused an immediate and heavy loss of minnows, particularly fallfish, common shiners (*Notropis cornutus*), and silverling minnows (Surber, 1946). The smallmouth black bass in Back Creek was affected most. About half the fish found dead were smallmouth bass. They were found along the feather edges of gravel bars, together with stoneroller suckers and common suckers. They apparently were able to obtain protection from predators because of the shallowness of the water. The greatest mortality occurred 3 days after treatment, as compared with 9½ hours after an oil spray. The amount of DDT reaching the stream at Patuxent was greater, however—0.6 pound per acre as compared with 0.39 pound per acre on the surface of Back Creek.

Practically no fish reached the stopnet at the lower end of the test section. The loss was probably greater than observed, because the evidence was quickly removed by turtles and carnivorous fish. Since the schools of bluntnose minnows and individual small groups of spotfin minnows, silverling minnows, and young blacknosed dace were found in the same areas in which they occurred before spraying, it was concluded that the treatment had no important effect on the minnow species. In Ash Creek, a trout stream in Lackawanna County, Pennsylvania, a 1-pound-per-acre treatment in oil (actual deposit 0.23 pound DDT) killed large numbers of fallfish, common shiners, and

TABLE 3.—*Numbers of native fishes lost in **Back Creek** after spraying with wettable DDT on July 24, 1946, 6:40 a.m.*

Date	Small-mouth bass	Stone-roller sucker	Common sucker	Spotfin minnow	Blunt-nosed minnow	Red-bellied sunfish	Brown bullhead	Fantail darter	Total
July 24	....	....	....	....	....	....	....	....	....
do. 25	....	1	....	....	....	1	....	....	2
do. 26	....	....	....	1	....	....	....	....	1
do. 27	11	10	5	....	1	....	1	....	28
do. 28	11	4	1	....	....	....	....	1	17
do. 29	5	....	....	2	....	....	....	....	7
do. 30	1	....	....	....	....	....	....	....	1
do. 31	3	2	....	....	....	....	....	....	5
Aug. 1	....	....	....	....	....	....	....	....	....
Total (all sizes)	31	17	6	3	1	1	1	1	61
Fingerlings									
Number	30	17	6	....	....	....	1	1	....
Average size (inches)	1.5	1.6	2.1	....	....	....	1.3	1.1	....
Yearlings or older									
Number	1	....	....	3	1	1	....	....	....
Average size (inches)	3.6	....	....	2.5	2.1	2.8	....	....	....

TABLE 4.—*Effects of wettable DDT on fishes placed in live boxes in Back Creek*

Station	Distance from Glengary Bridge	Kind of fish	Length (inches) Average	Length (inches) Range	Number before spraying	Number of fish lost: From DDT	Number of fish lost: From handling, predation, or other causes	Percentage of survival
A	0.2 mile above	Largemouth bass	3.2	2.0-4.3	28	....	2	92.9
		Bluegill sunfish	2.7	3.3-3.9	14	....	2	85.7
		Golden shiners	4.0	2.5-5.7	28	....	2	92.9
		Goldfish	7.6	5.8-8.4	8	....	....	100.0
B	0.1 mile below	Largemouth bass	2.1	2.0-2.4	14	....	4	71.4
		Bluegill sunfish	2.4	2.1-2.8	63	....	....	100.0
		Golden shiners	3.3	2.7-4.3	14	....	2	85.7
		Goldfish	6.1	5.1-7.1	4	....	....	100.0
C	0.5 mile below	Largemouth bass	2.7	2.4-3.2	14	3	....	78.6
		Bluegill sunfish	2.7	1.9-4.9	61	....	1	98.4
		Golden shiners	4.3	3.7-4.8	10	....	2	80.0
		Goldfish	....	....	3	....	3	0.0
D	0.9 mile below	Largemouth bass	3.2	2.6-3.6	14	2	10	14.3
		Bluegill sunfish	2.6	2.0-3.6	69	....	....	100.0
		Golden shiners	4.8	4.7-5.0	14	....	10	28.6
		Goldfish	7.5	6.0-9.0	4	....	....	100.0
E	2.0 miles below	Largemouth bass	2.6	2.4-2.8	14	....	1	92.9
		Bluegill sunfish	2.5	1.9-3.8	58	....	2	96.6
		Golden shiners	4.8	4.3-5.4	14	....	....	100.0
		Goldfish	7.1	5.9-7.6	4	....	....	100.0
Total					452	5	41	89.8

suckers, as well as a few trout, whereas a suspension (0.39 pound), caused negligible losses in Back Creek. Losses occurred sooner with the oil spray. Although 9,000 brown bullheads (*Ameiurus nebulosus*) were placed in Back Creek immediately above and within the sprayed section on July 12, only one was found dead after the spraying.

There was no evidence that the DDT affected adult fish, since not a single one was found dead.

Of the 452 fish placed in live-boxes (Table 4), apparently only five died from the toxicity of the DDT. Predators removed a considerable number of fish from one live-box, and the handling of the fish was responsible for other losses. However, the survival, even with these losses, amounted to 89.8 percent.

Incidental observations were made on other animals. Eastern painted turtles (*Chrysemys picta*) were abundant in this section. Musk turtles (*Sternotherus odoratus*) and wood turtles (*Clemmys insculpta*) were common. Two large snapping turtles (*Chelydra serpentina*) were observed above the stopnet several days after the spraying. Bull frogs (*Rana catesbiana*) and water snakes (*Natrix sipedon*) were also observed, but none of the species were affected.

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AQUARIUM STUDIES ON THE TOXICITY OF DDT TO BROWN TROUT, *SALMO TRUTTA*

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Abstract

Experiments were conducted on the toxicity to fingerling brown trout of DDT when applied in an aqueous suspension, as an emulsion, as a solution in which the DDT is dissolved in a petroleum oil such as kerosene, and finally as as dust. The experiments were conducted at the Cornell University Experimental Hatchery in 15-liter aquaria containing 10 liters of water placed in a trough of running water to maintain a nearly constant temperature. Ten brown trout were used in each aquarium in each experiment. Measure of toxicity was taken as time required for a 50-percent mortality.

Results of these laboratory experiments showed DDT to be most toxic to brown trout when applied in an emulsion. Concentrations of 1:20,000,000, equivalent to 0.05 pounds per acre, resulted in 50-percent mortality in 30 hours. Aqueous suspensions of DDT in concentrations of 1:20,000,000 gave a 50-percent mortality in 64 hours. Xylene was shown to be a contributing source of toxicity when used as a solvent of DDT. Concentrations of 1:2,800 of xylene gaxe 50-percent mortality in 17 hours. Other xylene concentrations ranging from 1:7,000 to 1:5,700,000 resulted in no mortality in the observation period of 96 hours. Xylene plus emulsifier was toxic to brown trout in concentrations up to 1:27,000 in 3¼ hours. Concentrations of 1:135,000 to 1:2,700,000 gave no mortality in 96 hours. DDT applied as a dust in concentrations of 1:1,000,000, or approximately one pound per acre, was not found toxic to brown trout as applied in laboratory tests. The toxicity of kerosene solutions of DDT is increased considerably by agitation.

Introduction

DDT has been found to be more toxic to cold-blooded than to warm-blooded animals. The wholesale spraying of swamps and ponds with DDT can be expected to kill a great many fish, frogs, and other cold-blooded form (Ellis, Westfall, and Ellis, 1944). Eide, Deonier, and Burrell (1945) concluded that DDT in dusts and oils at dosages of 1 and 2 pounds per acre is not harmful to fish. Ginsburg (1945) said that DDT is most toxic in colloidal dispersions, less toxic in surface applications in the form of oil emulsions, and least toxic when applied as a dust. Invertebrates and cold-blooded vertebrates are more readily affected than are birds and mammals (Cottam and Higgins, 1946). These authors state further that less than 0.2 pounds of DDT per acre in an oil solution should be used to avoid damage to fishes, crabs, or crayfish and less than 2 pounds per acre to avoid damage to birds, amphibians, and mammals. They cautioned against applying DDT in any concentration directly to streams, lakes, and coastal bays. Using 0.6 pounds of DDT per acre on open ponds may result in as much as 30-percent reduction of the fish population

(Hearld, 1946), and repeated treatment of an open pond with 0.6 pounds of DDT per acre may so reduce the normal population of fish that the species would not be able to maintain themselves.

A review of the above literature indicates the general toxicity of DDT to fish. The purpose of this study is to determine quantitatively the toxicity of DDT to brown trout, *Salmo trutta*.

When DDT is used as an insecticide it is commonly applied in one of the following ways: as an aqueous suspension containing 20 percent of DDT mixed with 80 percent of inert material plus a wetting agent; as an emulsion in which the DDT is dissolved in an organic solvent plus an emulsifying agent; as a solution in which the DDT is dissolved in a petroleum oil such as kerosene; or as a dust containing from 3 to 20 percent DDT combined with inert material such as talc or pyrophyllite. In the course of the study the fish were exposed to DDT prepared by each of the four methods listed above.

Materials and Methods

The experiments were conducted at the Cornell University Fish Hatchery. Fifteen-liter aquaria containing 10 liters of hatchery water were placed in a trough of running water to maintain a suitable water temperature during the course of the experiment. Five hundred brown trout were obtained from the Federal Hatchery at Cortland, New York. These fish were secured in two allotments: the first group averaged 1½ inches in length, the second 1¾ inches. These fish were held for a period of 10 days at the Cornell Hatchery before being used in any experiment, and were maintained in the same environment for the duration of the study. They were fed on finely ground beef liver and at varying intervals on *Daphnia*. Throughout the investigation, which was carried on over a period ranging from March 13 to June 2, only four trout were lost from other than experimental causes. The cause of their death was not determined.

Ten trout were placed in each of two aquaria to determine the time they could be expected to live without ill effects in 10 liters of water without aeration. At the end of five days they were removed to a trough for further observation. No distress was evident during the trials.

Controls, consisting of trout placed in 10 liters of hatchery water in one aquarium or in aquaria with known concentrations of chemicals used in conjunction with the DDT, were run for each experimental test. After filling the aquaria with 10 liters of hatchery water, the test concentration of DDT was added and the trout were introduced to each aquarium (except in the dust experiment in which the fish were placed in the aquaria first). The 10 trout were selected haphazardly from the hatchery trough for each trial. The time at which the trout were added to the aquarium was considered the beginning of the experiment. Observations on their actions and time of death

were recorded as closely as possible for each fish. Death point was taken as that time at which the fish made no perceptible movement.

Wide individual resistance to the toxicity of DDT was noted. The time at which 50 percent of the trout were dead was taken as a measure of the concentration.

The temperature was recorded at intervals during the running of each experiment and from these readings an average temperature was computed. In all of the experiments the range of the temperature variation was limited to 2° F., except in one kerosene experiment when a drop of 6° F. was recorded.

Toxicity of DDT with Different Methods of Application

DDT in aqueous suspension.—The first series of experiments was conducted using DDT in association with a wettable powder. The mixture formed an aqueous suspension in the aquaria. The powder employed was a commercial product manufactured by the Geigy Company and sold under the trade name of Gesarol. Composition by weight of this powder was 20 percent DDT and 80 percent wettable material and inert matter.

The wettable powder was used in concentrations varying from 1:2,500 to 1:20,000,000. In this experiment the time at which 50 percent mortality occurred was in direct proportion to the concentration of DDT, and its range was from 4¾ hours at a concentration of 1:2,500 to 64 hours at a concentration of 1:20,000,000. The various concentrations of DDT used and the observed results are listed in Table 1.

Table 1.—*Toxicity of DDT with "Gesarol"*[1] *to brown trout*

Concentration	50-percent mortality (hours)	Temperature (F.°)
1:2,500	4¾	41
1:10,000	8	41
1:20,000	10	41
1:40,000	14¼	41
1:100,000	35¾	40
1:500,000	33½	40
1:1,000,000	34¾	40
1:5,000,000	45¼	41
1:10,000,000	47½	41
1:20,000,000	64¼	52

[1]Twenty percent DDT and 80 percent wettable powder and inert material.

DDT in an emulsion.—The second experimental series undertaken was the use of DDT in an emulsion. DDT was dissolved in xylene and an emulsifying agent was added. The first series was set up at a concentration of one part of DDT to 10,000 parts of water. Controls were used which contained the same amounts of xylene and emulsifier as those present in the experimental tanks. At this concentration all the fish died except those in the control aquaria containing water only, and water plus emulsifier. Since this experiment established

xylene and xylene plus emulsifier as contributing sources of toxicity, different concentrations of these substances were prepared and a series run on each.

The concentrations of xylene used were equivalent to the amounts of the solvent required to dissolve the DDT in each of the experiments. Xylene was toxic to brown trout at a concentration of 1:2,800; 50-percent mortality occurred in 17 hours. The xylene caused no mortality at concentrations of 1:7,000 to 1:5,700,000 during an experimental period of 96 hours. The addition of an emulsifier prevented the xylene collecting on the surface of the water. Concentrations of xylene plus emulsifier of 1:27,000 gave a 50-percent mortality in 3¼ hours. Additional controls corresponding to the higher DDT concentrations were used. No mortality was observed for xylene plus emulsifier, during the 96-hour experimental period, at concentrations ranging from 1:135,000 to 1:2,700,000.

DDT dissolved in xylene with an emulsifying agent added was the most toxic to trout of all the items employed. A 50-percent mortality at concentrations of 1:20,000,000 occurred in 30 hours (Table 2). The relatively high toxicity of DDT in an emulsion is more apparent when it is realized that the concentration of 1:20,000,000 parts of DDT is approximately 0.05 pounds per acre.

TABLE 2.—*Toxicity of DDT in xylene emulsion*[1] *to brown trout*

Concentration	50-percent mortality (hours)	Temperature (F.°)
1:10,000	¼	48
1:1,000,000	7½	55
1:5,000,000	9	55
1:10,000,000	10	55
1:20,000,000	30	52

[1]DDT 20 percent, xylene 70 percent, and emulsifier 5 percent.

DDT dissolved in kerosene.—In the first experiment conducted, one gram of DDT was dissolved in 15 cubic centimeters of kerosene and this solution placed in 10 liters of water. Two control aquaria were used, one containing 15 cubic centimeters of kerosene added to the water and the other hatchery water. No mortality occurred in any of the aquaria in 72¼ hours. The experiment was discontinued when the water temperature dropped 6° F. The fish were removed from the aquaria and placed in a separate trough so that any delayed effects of the solution could be determined. Forty-eight hours after the conclusion of the experiment one fish from the aquarium containing the kerosene and DDT died, but the cause of death was not determined.

A second experiment with a DDT level of 1:13,333 was observed for a period of 101 hours. No mortality occurred within this period, but four fish died 48 hours after the experiment was ended.

The 1:10,000 concentration of DDT was rechecked with an increase in water temperature of 8° F. At the higher temperature all of the DDT remained in solution. At the end of 96 hours the experiment

was discontinued. No mortality occurred in any of the aquaria. Observation of the aftereffects showed a loss of three fish in 36 hours. These fish were from the aquarium containing the DDT and kerosene. Finally, agitation was applied at intermittent intervals to all of the aquaria. A 50-percent mortality was observed in the aquarium containing kerosene and DDT in 31½ hours. All of the fish were dead in 42½ hours. This, the only mortality experienced in the kerosene solutions, was attributed to the use of agitation. Considerable precipitation of DDT occurred during the process of agitation. In the aquarium where kerosene was used as a control three fish died within a 60-hour period. Two more fish died 20 hours after removal from the aquarium.

DDT applied in a dust.—The fourth method of distributing DDT was in the form of a dust. A mixture of 20 percent DDT and 80 percent pyrophyllite was sifted upon the water surface by using No. 60 screen. A corresponding amount of pyrophyllite was used in a control experiment. Various concentrations were used but no mortality was experienced until a concentration of 1:500,000 was reached. At this concentration the 50-percent-mortality time was 63¼ hours (Table 3). The amount of DDT used corresponded roughly to 2 pounds per acre. At a concentration of one pound to the acre no mortality occurred during the observation period of 100 hours. Also, no mortality resulted in any of the controls.

TABLE 3.—*Toxicity of DDT dust*[1] *to brown trout*

Concentration	50-percent mortality (hours)	Temperature (F.°)
1:100,000	38¼	55
1:200,000	50¼	55
1:300,000	54	55
1:400,000	58½	55
1:500,000	63¼	55
1:1,000,000	none at 100 hours	56
1:10,000,000	none at 100 hours	56

[1]Twenty percent DDT and 80 percent pyrophyllite.

SYMPTOMS OF DDT POISONING

The symptoms of poisoning by DDT followed a rather definite pattern. At first the fish became rather restless, darting wildly about the aquaria, sometimes crashing against the sides. The fish in the control aquaria were usually quiet and placid, lying on the bottom with only the pectoral fins fanning. When a light was turned on at night for observation, the fish in the experimental aquaria were more noticeably affected than were those in the control aquaria. Eventually the experimental fish swam to the surface of the water in an almost vertical position. On tiring, they floated downward in a falling-leaf fashion. A marked loss of equilibrium, followed by convulsions, was observed. The fish moved about the bottom on their sides and backs with occasional convulsive flutterings. In the final stages of DDT

poisoning the fish lay motionless on the bottom of the aquaria with only the mouth and operculum showing any perceptible movement.

A superficial examination of the fish after death gave evidence of hemorrhage in the gill region. The gills were rather heavily coated with mucous. Often the fish were contorted and arched after death. This may have been the result of the convulsions observed.

Acknowledgments

The authors are indebted to Dr. Arthur M. Phillips of the Federal Fish Hatchery, Cortland, New York, for supplying the experimental fish; to Professors L. B. Norton, W. A. Rawlins, and T. C. Watkins of the Department of Entomology, Cornell University, for advice and for supplying chemicals; to Dr. D. A. Webster, Laboratory of Limnology and Fisheries, Cornell University, for assistance and criticism in the preparation of this paper.

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PREDICTING DEPTH DISTRIBUTION OF FISH IN THREE TVA STORAGE-TYPE RESERVOIRS[1]

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Abstract

Depths at which largemouth bass (*Huro salmoides*), walleye (*Stizostedion vitreum*), and sauger (*S. canadense*) were most abundant in Norris, Douglas, and Cherokee Reservoirs were predicted on a weekly or bi-weekly basis during summer of 1946. Information was released through local newspapers. Predictions were based on relation of temperature and dissolved oxygen to distribution of fish taken in gill nets in 1943, 1944, and 1945. On June 2 the prediction was the same for all three reservoirs. Because of changes in thermal stratification and in supply of dissolved oxygen, fish distribution could not be expected to remain similar in any two reservoirs. Field analyses and a method of presenting predictions are described. Managers and guides at five out of the six fishing docks felt this service improved the fishing success, especially of individuals unaccustomed to storage reservoirs. With refinements and evaluations for specific applications such a program might pay good dividends on private or public waters.

The depths at which largemouth bass (*Huro salmoides*), walleye (*Stizostedion vitreum*), and sauger (*S. canadense*) were most abundant in Norris, Douglas, and Cherokee Reservoirs have been predicted on a weekly or bi-weekly basis during the summer of 1946. The information was released to anglers through local newspapers (Fig. 1). The purpose of this service was to provide reasonably accurate information regarding depth distribution of fish in the hope that it might enable sport fishermen to catch more game fish, thereby improving the recreational use of these impoundments. This is a part of the general effort to increase the utilization of game fish in TVA impoundments. The basis for these predictions and the method used in making them are described below.

Eschmeyer and Tarzwell (1941) explained the unexpected differences in quality of fishing at different depths and in different areas of Norris Reservoir by applying data on density currents (Wiebe, 1940) to fishing records. After describing the relation of density currents of oxygen-poor waters to the distribution of fish as indicated by anglers' success, they stated: "The catch per angler would probably have been much better early in 1939 had the fishermen known how and where to fish." Thus, the need for information regarding fish distribution was recognized several years ago.

The predictions discussed here are based on the 1943 and 1944 findings on Norris (Dendy, 1945, 1946a) regarding the relation of

[1]Published with permission of the Tennessee Valley Authority. Presented at the Seventy-sixth Annual Meeting.

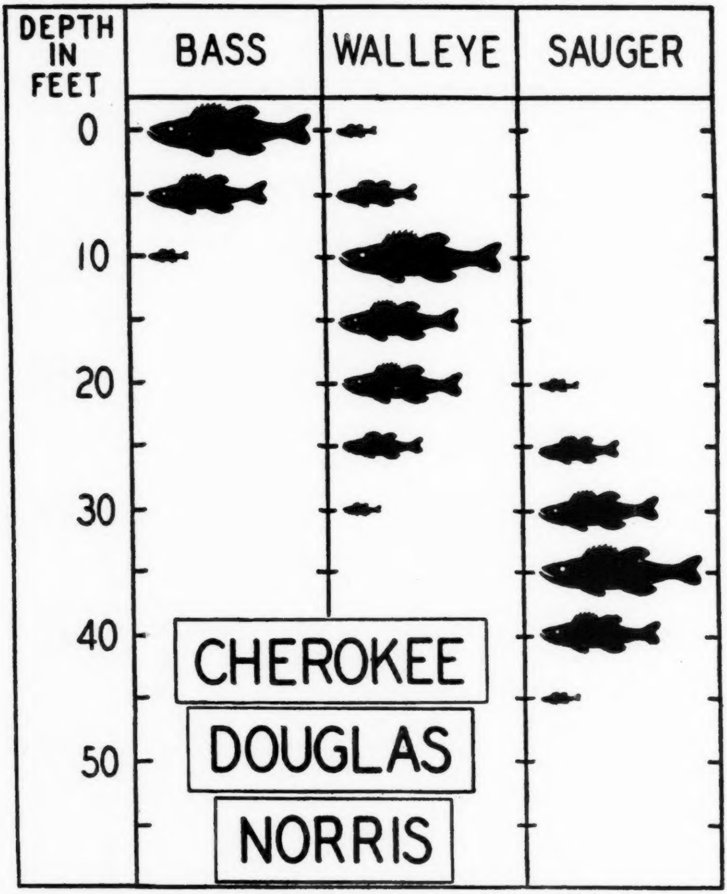

FIGURE 1.—Depth distribution of fish predicted for June 2, 1946. Size of fish indicates abundance at depth shown. A clipping from *The Knoxville Journal;* also published in *The Knoxville News-Sentinel.*

temperature and dissolved oxygen to the depth distribution of fish taken in gill nets. These netting records showed two things of importance to depth distribution: first, that in the presence of an adequate supply of dissolved oxygen the depth distribution of fish was related to thermal stratification (Fig. 2); second, that the oxygen

requirements of some species, notably sauger, are low—1.5 p.p.m. or less in cool water (60°-65° F.). It may be added here that in early spring as well as in summer the water temperature is closely related to the quality of fishing. Dendy (1946) found that in early spring the waters of Norris are much warmer in the upstream areas than in the lower reaches of the reservoir. Good fishing in 1945 started earlier at the upstream docks than in the downstream waters. Since angling is best when the water has warmed to about 60° F., a pocket thermometer may be of considerable help to the early spring angler.

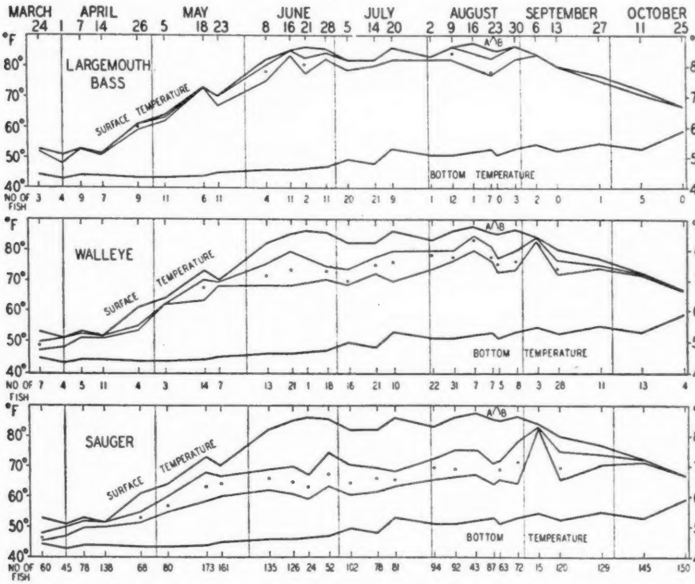

FIGURE 2.—Distribution of the middle 50 percent of largemouth bass, walleye, and sauger in relation to temperature, Norris Reservoir, 1943. The two middle lines show temperature range of middle 50 percent of fish caught. When range was wide the temperature where median fish was caught is indicated by dot. Presence of walleye in unusually warm water on August 16 and September 6, and of sauger in the same zone on September 6, resulted from oxygen shortages in the strata formerly occupied by these species. For further explanation see Dendy (1945, Fig. 13, p. 128).

In 1945 netting studies in Cherokee and Douglas Reservoirs indicated that the relation of fish distribution to temperature and dissolved oxygen in these reservoirs was similar to that found in Norris.

The graph for the first prediction released to the press in 1946 (Fig.

1) showed fish distribution to be the same in all three reservoirs. However, because of changes in thermal stratification and in the availability of oxygen, the distribution of fish could not be expected to remain the same in any two reservoirs. In Cherokee and Douglas Reservoirs the changes in thermal stratification follow the general pattern shown for Norris in 1943 (Fig. 3). Differences in volume and temperature of inflowing water and in volume of discharge alter the slope of the isotherms for various reservoirs.

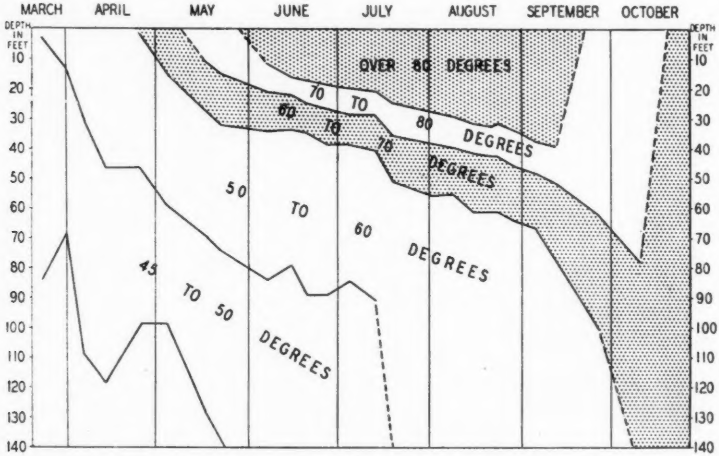

FIGURE 3.—Isotherms (F.°) for Norris Reservoir, 1943.

In the netting studies, over half of the walleye and sauger were caught in the lower third of the 8-foot gill net (Haslbauer, 1945). This fact indicates that when trolling or stillfishing the lure must not only be at the proper depth but also should be within 2 or 3 feet of the bottom.

Predictions were begun in early June about the time fishing quality starts to decline. With a year-around open season it is obvious that our best fishing will be in the spring when largemouth bass are actively feeding near the surface. During this season anglers do well casting surface lures and need no advice as to the depth at which to fish. As the epilimnion thickens bass distribute themselves through this layer. Surface fishing declines and deep trolling increases in importance.

Field work for this project was done according to standard limnological methods. Temperature was determined by means of a resistance thermometer. Water samples were obtained with a modified Kemmerer

sampler or "Juday bottle." The Winkler method[2] was used for determining the concentration of dissolved oxygen. A chemical kit in the trunk of a car constituted a mobile laboratory. Many samples were not titrated. In fact, upon addition of the second reagent, the alkaline iodide, the floculent precipitate was often of such a dark brown color that it was obvious that the sample contained an abundance of oxygen. For the problem at hand, it was immaterial whether the concentration of dissolved oxygen was 6, 7, 8, or 9 p.p.m. When a sample produced a light brown or whitish precipitate, indicating a low concentration of dissolved oxygen, the analysis was completed carefully. Where conditions warranted it, the water samples were taken at 5-foot intervals, otherwise at 10-foot intervals.

Most sampling stations were located at conveniently situated bridges. When developments made it desirable, additional stations were reached by boat. On Cherokee Reservoir necessary data to supplement our records on the downstream area were made available by the TVA Stream Sanitation Laboratory of the Health and Safety Department.

Curves for field data were plotted and the predictions were made by comparing graphs of existing conditions to the graphs of the distributions of the middle 50 percent of the population of largemouth bass, walleye, and sauger in relation to temperature in 1943 (Fig. 2). Thus in the latter part of July, where oxygen was present in sufficient concentration, sauger would be most abundant at the depth where the temperature was about 65° F. Similarly, walleye would be in water about 77° F. and largemouth bass would be in the upper layer where the temperature was 80° F. or above.

Making the prediction was not difficult where oxygen was plentiful, as in Norris Reservoir on the late-July graph (Fig. 4).

A series of blanks for the graphs were reproduced photographically without the fish symbols. Similarly, a number of fish silhouettes of different sizes were kept on hand. The symbols were clipped out and pasted on the blank at the proper places. Size of fish indicated abundance at depth shown. However, where oxygen supply was low and the temperature rather high (Douglas and Cherokee Reservoirs—Fig. 4.), it was necessary to anticipate the changes which would probably take place. Advice on the expected rates of water movements and of changes in thermal stratification was secured from TVA Hydraulic Data Division of the Water Control Planning Department. Conditions in various areas of a reservoir may differ widely in stratification of dissolved oxygen. For this reason an explanatory paragraph accompanied each fish graph.

The value of these predictions is difficult to measure. No check on their effectiveness has been made. The two seasons of netting on Norris Reservoir and the additional netting on Douglas and Cherokee

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[2]This method was outlined by the American Public Health Association and the American Water Works Association. 1936.

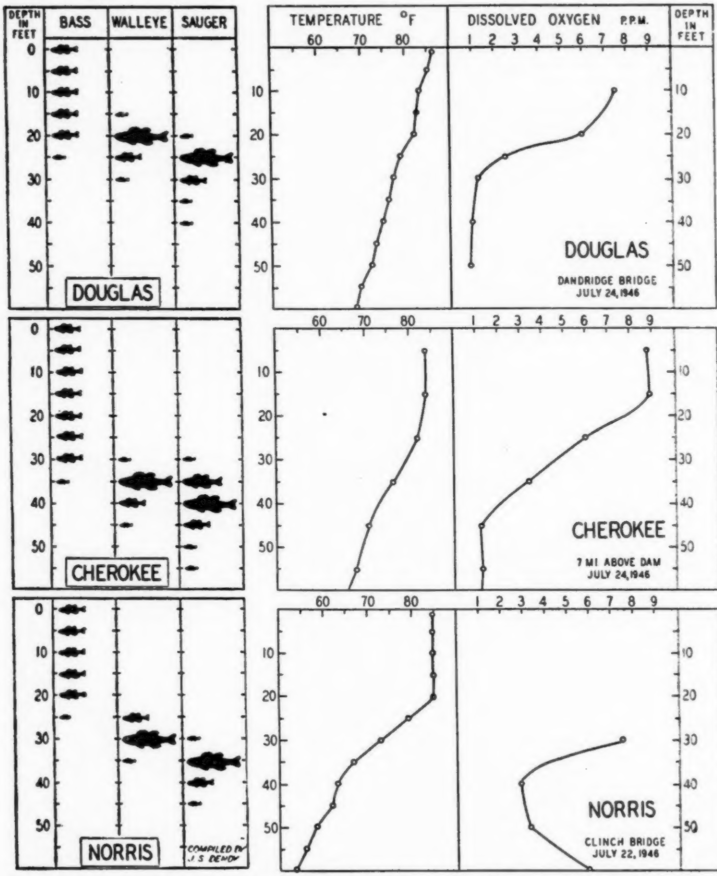

FIGURE 4.—Depth distribution of fish predicted for July 28, 1946, with curves for data on temperature and dissolved oxygen. The fishing graph, a clipping from *The Knoxville News-Sentinel,* was also published in *The Knoxville Journal,* and *TEC News.* The curves for temperature and dissolved oxygen, not a part of the newspaper publication, give data from which the prediction was made.

Reservoirs indicate that our predictions are sound. Isolated instances show that fishing at predicted depths produces better results than fishing at other depths.

Results from questions to dock managers and fishing guides on

Norris Reservoir show that anglers who had read the Knoxville papers were familiar with the graphs and usually fished according to the predictions. Managers and guides at five out of six docks felt that this service improved fishing success, especially of individuals unaccustomed to fishing on storage reservoirs. The one manager who did not think the predictions had helped his fishermen caters to Kentucky anglers, only 10-20 percent of whom know and use this service. He said he knew of the graphs but did not post them. He requested that the 1947 predictions be released through Kentucky papers in order that his fishermen might benefit from them. All dock managers and guides requested that this service be repeated in 1947.

Responses of fish to temperature and dissolved oxygen are not necessarily the same in two nearby lakes or reservoirs. Hile and Juday (1941) found an interesting lack of agreement in the relationship between temperature, dissolved oxygen, and free carbon dioxide and the depth distribution of various species in different lakes. Obviously refinements and evaluations for specific applications will be needed before this type of work can be done on a large scale. Research on such a program might pay good dividends on private or public waters.

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THE FECUNDITY OF HERRING FROM VARIOUS PARTS OF THE NORTH PACIFIC

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ABSTRACT

A comparison is made of the fecundities of herring from Seal Rock, Washington, British Columbia, Hokkaido, Japan, and Peter the Great Bay, Siberia. Among herring of the same size, the Seal Rock fish produce more eggs than the British Columbia herring; and the British Columbia specimens bear more eggs than the Siberian herring. Among herring of the same age, the Siberian herring is far more fecund than either the herring of Seal Rock or Hokkaido. Fecundity is suggested as an additional criterion to aid in the differentiation of herring races.

The differences in the number of vertebrae, the variations in body proportions, the rate of growth, and the times of spawning have been among the various criteria used to distinguish the races of herring of the Atlantic and Pacific species. In recent years, facundity has been added to the list of racial criteria, for the number of ova has been found to differ in the various seasonal herring races. Farran (1938) and Hickling (1940) investigated the fecundity of the European herring and found significant differences in the numbers of eggs produced by the summer- and winter-spawning herrings. It is believed that the use of the number of ova as a racial criterion can be extended to differentiate between herring of various localities. In the following pages, we shall present some data which illustrate differences in the fecundity of herring, *Clupea pallasii* Cuvier and Valenciennes, from different areas of the North Pacific.

The herring taken from various areas in the North Pacific basin have shown interesting variations in the number of ova produced (Table 1). Ambroz (1931) published the results of a series of 136 ova counts from herring of Peter the Great Bay, Siberia. He calculated the mean number of eggs of the several size classes of the herring of his collection. Hart and Tester (1934) published data on a small series of ova counts from a collection of British Columbia herring.

A collection of 52 gravid female herring was made in Puget Sound at Seal Rock, Washington, during the spring of 1936 before any spawning had taken place. The number of ova of each fish was estimated in the following manner. The ova were dissected from the ovarian tissue and were weighed accurately. A sample of about 1 or 2 grams of ova was weighed and the number of ova were counted. From the weight of the sample, and the number of eggs in the sample, and the weight of the original ova, the total number of ova in the

[1]Study made while with the Washington State Department of Fisheries, Seattle.

ovaries could be calculated by a simple proportion. These data, too, are present in Table 1.

TABLE 1.—*Relation of length of fish to egg production in herring from Seal Rock, Washington, British Columbia, and Peter the Great Bay*

[The data for the fish from Peter the Great Bay were adapted from Ambroz (1931) and the figures for British Columbia herring, from Hart and Tester (1934).]

Standard length (millimeters)	Seal Rock, Washington		British Columbia		Peter the Great Bay	
	Mean number of eggs	Number of fish	Mean number of eggs	Number of fish	Mean number of eggs	Number of fish
131-140	8,005	1	....	....	....	....
141-150	7,782	9	....	....	....	....
151-160	8,767	9	....	....	....	....
161-170	13,611	9	....	....	....	....
171-180	15,743	12	....	....	....	....
181-190	23,515	4	....	....	....	....
191-200	26,262	3	18,600	2	14,206	1
201-210	36,097	3	....	....	18,918	6
211-220	36,538	2	25,620	4	17,587	5
221-230	....	....	29,500	1	25,913	2
231-240	....	....	....	....	26,784	1
241-250	....	....	....	....	32,106	10
251-260	....	....	....	....	33,211	3
261-270	....	....	....	....	44,150	3
271-280	....	....	....	....	55,571	8
281-290	....	....	....	....	58,323	33
291-300	....	....	....	....	58,497	18
301-310	....	....	....	....	58,644	7
311-320	....	....	....	....	71,593	12
321-330	....	....	....	....	89,051	8
331-340	....	....	....	....	101,560	7
341-350	....	....	....	....	102,706	8
351-360	....	....	....	....	110,550	3
361-370	....	....	....	....	134,100	1

A comparison of the fecundities of the herring from the different collections shows a substantial and consistent difference in the numbers of eggs produced by fish of the same size but from different localities. It is noted (Fig. 1) that the Seal Rock herring produce more eggs than the British Columbia herring of the same length, and that the Siberian herring from Peter the Great Bay are less efficient egg producers than the British Columbia herring of the same size.

The Seal Rock herring's high egg production is, however, a dubious distinction, for the relatively small Seal Rock fish which grow only to 220 millimeters fail to approach the average size of the British Columbia herring which range from 191 to 223 millimeters, or the huge Siberian specimens which grow to 370 millimeters. Even though the Seal Rock herring are the most efficient egg producers per unit of length, the Britsh Columbia and Siberian fish ultimately grow much larger and produce far more ova.

Herring of the same age as well as of the same length exhibit pronounced local differences in fecundity. Ambroz segregated his specimens by age as well as length, and calculated the mean fecundity of each age group in his collections. In his paper, Ambroz compared the fecundity of the Siberian herring with that of comparable age groups of Hokkaido herring in the collections of Fujita and Kokubo (1927). These data were compared with the egg counts of the various ages represented in the collection of Seal Rock Herring. (The ages

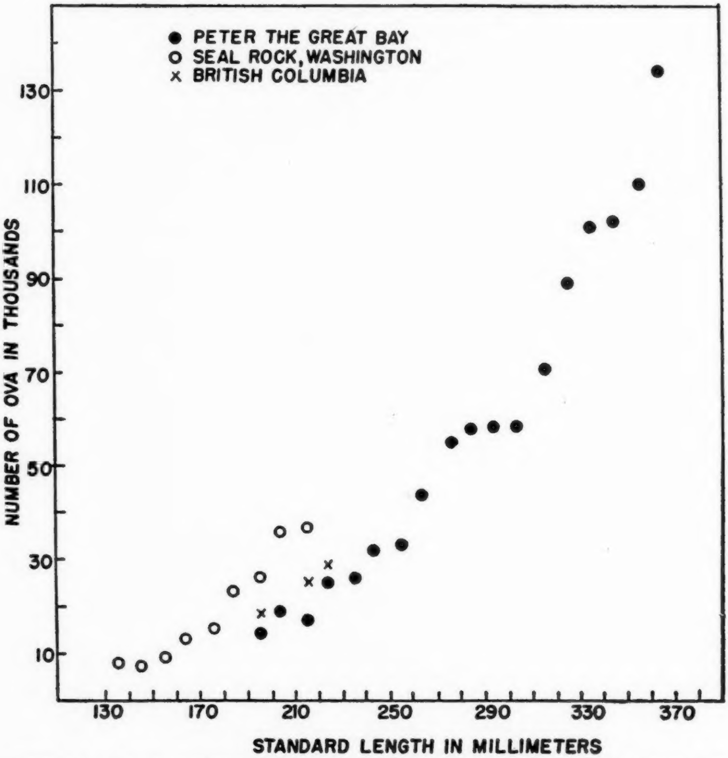

FIGURE 1.—The fecundity-length relationship of herring from Peter the Great Bay, Seal Rock, Washington, and British Columbia.

were determined from the scales.) Data on the age composition of the British Columbia herring were not available. This information, tabulated in Table 2 and illustrated in Figure 2, shows that the herring of Peter the Great Bay are far more fecund than are either the Seal Rock or Hokkaido herring of the same age. A 7-year-old Siberian herring, for example, produces almost three time as many eggs as a Seal Rock or Hokkaido herring of the same age. A 2-year-old Siberian herring produces as many eggs as a 5-year-old Seal Rock herring or a 4-year-old Hokkaido fish. In general, the Japanese herring are more fecund than the Puget Sound fish of the same age up to 6 years, but after that year fecundities are more comparable.

The growth rate of herring of various races is known to differ. The

Siberian herring used in our comparisons are larger than the Seal Rock herring of the same age and are faster growing than the rela-

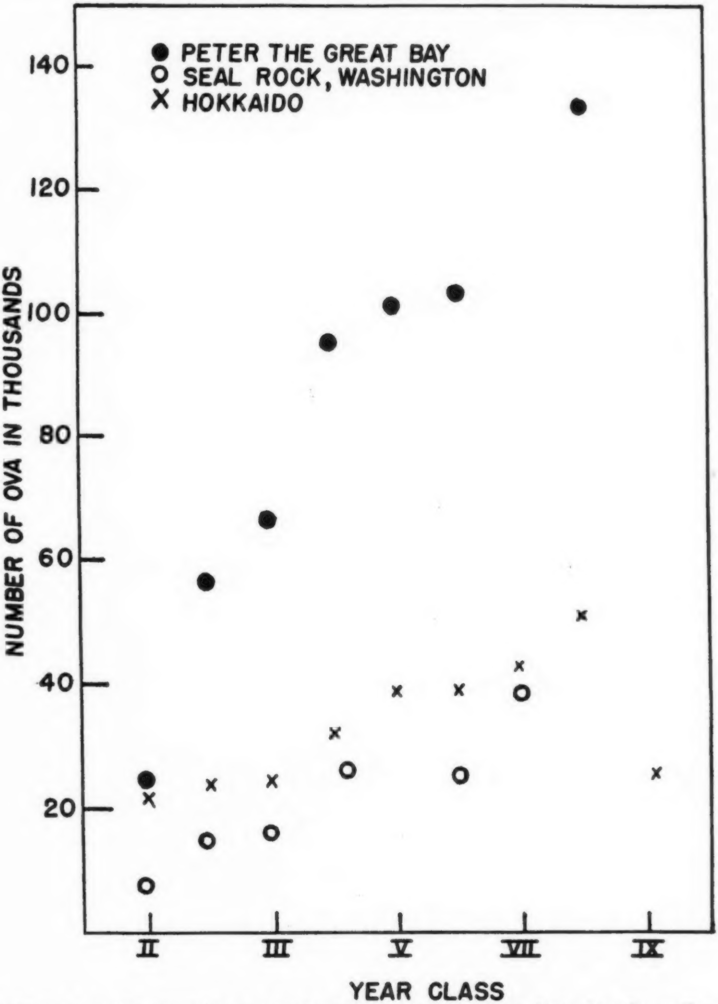

FIGURE 2.—The fecundity-age relationship of herring from Peter the Great Bay, Hokkaido, and Seal Rock, Washington.

TABLE 2.—*The fecundity of the various age groups of herring from Seal Rock, Washington, Peter the Great Bay, and Hokkaido*
[Data on Hokkaido herring from Fujita and Kokubo (1927).]

Age group	Seal Rock, Wash.		Peter the Great Bay		Hokkaido	
	Number of ova	Number of fish	Number of ova	Number of fish	Number of ova	Number of fish
I......	8,808	11	25,534	28	23,623	3
II......	15,815	17	57,435	57	24,304	26
III......	16,842	8	67,851	30	25,626	19
IV......	26,414	2	96,096	8	33,661	21
V......	38,376	1	102,610	10	39,825	25
VI......	35,279	2	104,106	4	39,499	27
VII......	39,914	1	....	....	44,638	19
VIII......	....	....	134,000	1	52,246	4
IX......	....	....	....	....	25,280	1

tively small Seal Rock fish. It is not proper to compare the fecundity of fish of the same age without taking into consideration the probable difference in size, for age alone obviously is not the only factor governing the fecundity of the herrings. But, regardless of size variation, there is a pronounced difference in the fecundity of herring of the same age. It would be of interest, however, to compare the fecundity of various races of herring with more similar rates of growth.

The existence of several races or populations of herring has been established by other criteria in Japanese, British Columbian, Alaskan, and Washington waters. It would be of value to study the fecundity of these races which are separated by only a few miles and which have more similar rates of growth and determine whether they vary in the production of eggs. It would not be expected that these races will show the striking variations that were observed in the collections discussed above, but perhaps they may yield data which under appropriate statistical treatment, might define otherwise obscure racial pictures.

Acknowledgement is made of the contribution of Donald W. Erickson to this study. He helped with the collection of the Seal Rock data and made most of the ova counts used in this work.

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AGE AND GROWTH OF STEELHEAD TROUT, *SALMO GAIRDNERII* RICHARDSON, CAUGHT BY SPORT AND COMMERCIAL FISHERMEN IN TILLAMOOK COUNTY, OREGON

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Abstract

During the winter of 1941-42, measurements and scale samples were collected from sport and commercial catches of steelhead trout (*Salmo gairdnerii* Richardson) caught in Tillamook County, Oregon. The commercial fish were taken in gill nets. It was found that the angler took both smaller (11.25-34.5 inches, fork length) and younger fish (2-5 years old) on the average, than did the nets (21.5-36 inches, fork length; 3-9 years old). The angler also took a higher proportion of females (1.56 females to 1 male) than did the nets (1.35 females to 1 male).

The best represented age group in both sport and commercial catches was the IV group (57.2 percent of the sport and 52.7 percent of the commercial catch). The largest group by size (26.0-27.9 inches) was the same in both catches.

Of the sport catch 12.7 percent, and of the commercial catch 21.4 percent, had spawned previously.

Fifty-seven and one-tenth percent of the sport catch and 55.6 percent of the commercial catch had spent about 2 years in fresh water and 2 in salt water before reaching sexual maturity.

Introduction

For some years the steelhead trout (*Salmo gairdnerii* Richardson) has been reserved for sport fishermen in the states of California and Washington. In Oregon, however, the gill netter can still market the steelhead. In 1941 the Oregon Legislature passed Senate Bill No. 53, for the conservation of salmon and steelhead trout. This legislation was to have closed a few streams to commercial fishing entirely, to have prohibited, in most cases, the use of set nets, and to have so shortened the season that a minimum of steelhead could be netted. The commercial interests won on a referendum in 1942, but in 1945, as House Bill No. 378, the measure was again passed by the Legislature. The gill netters and packers then had a referendum placed on the 1946 ballot. Their efforts, however, were in vain, as the vote supported the legislation.

Previous Studies

Work on the life history of the steelhead trout has been carried out in California on the Eel, Klamath, and Shasta rivers (J. O. Snyder, 1925, 1933a, 1933b); on Waddell and Scott creeks (Taft, 1936; C. O. Snyder, 1938); and in Washington on Green River (Meigs and Pautzke, 1940, 1941). For Oregon, the Fish Commission's Biennial Reports contain poundages of steelhead taken commercially.

Sources of Data

The present work was started in November 1941 as a random creel census on streams in Tillamook County, Oregon. From November 1941 to February 1942, 63 sport-caught steelhead trout were examined (mostly in February). Because of the difficulty in securing angler-caught steelhead trout, additional data were obtained from 802 gill-netted fish. Most of the latter were taken by set nets in the tidewater section of Wilson River, a major tributary of Tillamook Bay; the rest were caught in similar gear set in the Bay near the mouth of Wilson River. The gill-net data were obtained during the period, January 30 to February 28, 1942. Netters brought their catches to packing houses, where the fish were examined before being iced for the New York and California markets. Because of interference with packing operations, weights were obtained from only 178 of the 802 fish (167, January 30-February 2; 11, February 20).

Sizes of Steelhead Trout in the Sport and Commercial Catches

Comparative measurements (Table 1) show that the anglers took smaller fish, on the average, than did the nets. The range for the sport catch was 11.25-34.5 inches, fork length, whereas that of the netted fish was 21.5-36 inches. The nets exerted a more rigid selective action on their catch than did the angler. The latter has been known to throw back small fish in the hope of hooking a larger. On the other hand, the nets caught many of the larger fish before they could progress upstream to the anglers' positions. The 1946 angling regulations have prohibited the taking of salmon and trout under 20 inches in length, from November 1 to April 20. This regulation, the primary purpose of which is the protection of cutthroat trout spawners, will also largely eliminate the differences in size and age between the sport catch and the net catch of steelhead trout. The females were longer than the males in both types of catch. The difference in average length between the 178 weighed fish, and all the fish, of the commercial catch may indicate the existence of races. Average weights by sex for the commercial catch are not given because of a few errors in sexing when the weights were taken early in the work.

TABLE 1.—*Average fork length (inches) and weights (pounds) of sport and commercial steelhead trout*

Method of capture	Females			Males			All		
	Number of fish	Average length	Average weight	Number of fish	Average length	Average weight	Number of fish	Average length	Average weight
Sport	17	26.3	6.7	18	22.7	5.1	35	24.4	5.9
Commercial	311	28.3	....	391	28.1	....	178 802	27.1 28.2	8.6 ....

The average weight of the sport-caught steelhead, 5.9 pounds, compares closely with that of 5.7 pounds on the Klamath River, California

(J. O. Snyder, 1933a). The figure at that locality, however, is based on the summer migration; the winter steelheads were said to average larger. In the Tillamook Bay commercial catch, the average weight of 178 fish was 8.6 pounds.

Sex Ratios

The sex ratios of both sport and commercial catches are presumed to have been modified by selection. The ratio for the sport fish was 1.56 females to 1 male, that of the netted fish, 1.35 to 1. It is probable that the nets took relatively more females than males because of the greater plumpness and greater average size of the former. The anglers preferred females since they provided bait. Fresh or home-cured eggs in clusters are the usual baits used in winter steelhead angling on Oregon coastal streams.

Age

The scales of the commercial steelhead trout revealed that 74 (9.2 percent) of the 802 specimens showed regeneration and so could not be

Table 2.—*Relationship between age and length in sport-caught steelhead trout*

Fork length (inches)	Age groups II	III	IV	V	Total	Percentage of total number
10.0-11.9	....	[1]1	....	....	1	1.6
12.0-13.9	....	....	....	....	....	....
14.0-15.9	....	....	....	....	....	....
16.0-17.9	1	1	....	....	2	3.2
18.0-19.9	....	4	....	....	4	6.3
20.0-21.9	2	....	....	....	2	3.2
22.0-23.9	....	2	4	....	6	9.5
24.0-25.9	....	6	6	1	13	20.6
26.0-27.9	....	4	20	....	24	38.1
28.0-29.9	....	1	4	2	7	11.1
30.0-31.9	....	....	1	2	3	4.8
32.0-33.9	....	....	....	....	....	....
34.0-35.9	....	....	[2]1	....	1	1.6
Total	3	19	36	5	63	....
Percentage of total number	4.8	30.1	57.2	7.9	....	....
Average fork length (inches)	19.3	22.3	26.5	28.9	....	....

[1]11.25 inches.
[2]34.5 inches.

Table 3.—*Relationship between age and length in commercially-caught steelhead*

Fork length (inches)	Age groups III	IV	V	VI	VII	VIII	IX	Total	Percentage of total number
22.0-23.9	....	5	....	....	....	....	....	5	0.7
24.0-25.9	11	48	15	3	....	....	....	77	11.0
26.0-27.9	35	174	62	1	....	....	....	272	38.8
28.0-29.9	17	96	58	8	2	....	....	181	25.8
30.0-31.9	4	39	43	17	1	....	....	104	14.8
32.0-33.9	....	2	23	14	1	1	....	41	5.8
34.0-35.9	....	5	12	1	2	....	1	21	3.0
36.0-37.9	....	1	....	....	....	....	....	1	0.1
Total	67	370	213	44	6	1	1	702	....
Percentage of total number	9.6	52.7	30.3	6.3	0.9	0.1	0.1	....	....
Average fork length (inches)	27.1	27.6	29.5	30.4	31.8	32.5	34.0	....	....

used. Seventeen specimens were of undetermined sex. Other gaps in the data reduced the number used for the present study to 702 specimens.

The angler tended to catch younger as well as smaller steelhead trout than did the netter (Tables 2 and 3). His hooked fish were from about 2 to 5 years old (last annulus at edge of scale), and the commercial fish from about 3 to 9 years old. The best represented group in both sport and commercial samples was the IV group, which comprised 57.2 percent of the sport fish and 52.7 percent of the commercial fish. The largest group by size was the same, and included fish from 26 to 27.9 inches in fork length. However, the average length of the IV-group fish was greater in the commercial catch.

Number of Annuli in Stream and Ocean

A major difficulty in reading the scales of adult steelhead trout lies in the interpretation of the stream growth, which, in general is less consistent than that in the ocean. Apparently, adult steelhead whose scales show one stream annulus are faster growing fish, on the average, than are those which spend more time in the stream, and the first annulus often encloses as much area on the scale as does the second annulus on scales from more slowly growing fish.

A large proportion of the scales from net-caught fish showed an intermediate band of growth between the last stream annulus and the ocean growth. Most of these intermediate patterns are the result of new "summer" growth in the stream. However, in many scales the stream growth shades into an area of more widely spaced circuli which probably represent growth in the brackish water of Tillamook Bay. It has been determined[1] that the largest downstream migration of young steelhead trout takes place in the spring. Evidently the majority of the migrants spend only a few months, at most, in the Bay, for only 28 (4 percent) of the 702 specimens show what is presumably a brackish-water annulus. A comparison of average lengths of fish that have such an annulus and of those that are without it has shown that growth in tidewater is more nearly like freshwater than ocean growth. Hence, the brackish-water annuli are considered as stream annuli in the tables. The numbers of specimens with a presumed tidewater annulus are shown at the bottom of Table 5.

The numbers of sport-caught steelhead in the various age groups and the numbers of these fishes that had spawned previously are given in Table 4. Fish that spent 2 winters in fresh water before their seaward migration comprise 68.2 percent of the total (Meigs and Pautzke, 1941, gave 71.4 percent); those that showed 2 salt-water annuli form 71.4 percent of the total (Meigs and Pautzke, 1941, recorded 65.0 percent). For the commercial catch (Table 5) the figures are: 66.3

[1]Meigs and Pautzke (1941) and unpublished data from downstream trapping operations on a tributary of Tillamook Bay.

TABLE 4.—*Age and previous spawning history of sport-caught steelhead trout*

Number of of stream annuli	Number of ocean annuli	Number of fish spawned previously	Total number of fish in age group	Percentage of total number	Average fork length (inches)
1	1	0	3	4.8	19.3
1	2	0	13	20.6	25.6
1	3	2	4	6.4	29.7
2	1	0	6	9.5	16.7
2	2	1	32	50.8	26.0
2	3	5	5	7.9	28.9
Total		8	63	......	......

TABLE 5.—*Age and previous spawning history of net-caught steelhead trout*

Number of of stream annuli	Number of ocean annuli	Number of fish spawned previously	Total number of fish in age group	Percentage of total number	Average fork length (inches)
1	2	1	67	9.5	27.1
1	3	14	44	6.3	30.8
1	4	5	5	0.7	32.1
1	5	1	1	0.1	32.5
2	2	12	[1]326	46.4	27.2
2	3	67	[2]115	16.4	30.4
2	4	22	22	3.1	31.4
2	5	2	2	0.3	32.8
2	6	1	1	0.1	32.5
3	2	6	[3]93	13.2	27.4
3	3	12	[4]19	2.8	29.5
3	4	4	4	0.6	31.4
3	6	1	1	0.1	34.0
[5]4	2	2	2	0.3	27.8
Total		150	702	......	......

[1]Seven are 1 stream, 1 tidewater
[2]Seven are 1 stream, 1 tidewater
[3]Eight are 2 stream, 1 tidewater
[4]Four are 2 stream, 1 tidewater
[5]Two are 3 stream, 1 tidewater

percent for those with 2 stream annuli and 69.5 percent for those with 2 ocean annuli.

Of the sport-caught steelhead trout, 12.7 percent had spawned previously—once only—(Meigs and Pautzke, 1941, found 6.9 percent), whereas of the commercial catch (Table 5) 21.4 percent had been through a spawning migration. Of the netted males 14.6 percent, and of the females 26.0 percent had spawned previously. Possibly some of the difference can be attributed to the difficulty of reading male spawning checks, which are not as well defined as are those of the female.

Of the netted males that had spawned previously, 61.4 percent had spawned once and 36.4 percent twice; of the females, 74.0 percent had spawned once, 22.1 percent twice, and 2.9 percent 3 times. One male in its ninth year and one female in its eighth year had spawned 4 times.

No indubitable spawning checks were found in the stream-growth pattern. However, Meigs and Pautzke (1941) cite some examples of spawning before migration to the sea among their data, and it is quite possible that some examples were overlooked in the present study. From a small stream in Tillamook County, 2 ripe males (5.25 and 6.12 inches, fork length) were caught on March 22, 1942.

TABLE 6.—*Age at sexual maturity of sport-caught steelhead trout*

Number of stream annuli	Number of ocean annuli	Number of fish	Percentage of total number
1	1	3	4.8
1	2	15	23.8
1	3	2	3.2
2	1	7	11.1
2	2	36	57.1
Total		63	......

TABLE 7.—*Age at sexual maturity of net-caught steelhead trout*

Number of stream annuli	Number of ocean annuli	Number of fish	Percentage of total number
1	1	2	0.3
1	2	82	11.7
1	3	33	4.7
2	1	24	3.4
2	2	390	55.6
2	3	52	7.4
3	1	10	1.4
3	2	99	14.1
3	3	8	1.1
4	2	2	0.3
Total		702	....

AGE AT SEXUAL MATURITY

Of the sport-caught steelhead trout (Table 6), 57.1 percent, and of the netted fish (Table 7), 55.6 percent had spent about 2 years in fresh water and 2 in salt water before reaching sexual maturity (Meigs and Pautzke, 1941, recorded 51.2 percent). The percentages were larger—80.9 percent of the sport fish and 81.6 percent of the commercial—for fish with 2 ocean annuli at sexual maturity, regardless of the number of stream annuli (Meigs and Pautzke, 1941, 67.4 percent[2]).

CONCLUSIONS

1. The life history of steelhead trout in streams of Tillamook County, Oregon is essentially the same as that of the steelhead found in similar waters of Washington, and presumably, California.

2. In the size and age groups entering the catch, as well as in the catch ratio of females to males, and in the numbers of fish previously spawned, the sport fishery has been more detrimental to conservation of the steelhead than has the commercial fishery. However, the new 20-inch minimum size limit for winter-caught trout in the sport fishery will mitigate this detriment to a great degree.

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[2]Percentages in Meigs and Pautzke (1941), Table IV, added.

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HYBRID SUNFISH FOR STOCKING SMALL PONDS[1]

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Hybrid sunfish from male bluegill and female redear parents have been used to stock new ponds. Using densities of the order of 2,000 fingerlings per acre, excellent growth has been obtained. In the absence of competition from other species, the hybrids have increased by 3-4 ounces in their first growing season, and have achieved a pound in weight three summers after stocking—without the use of fertilizers. The F_1 hybrids included only 2 per-cent females. They have spawned successfully, however, and in two ponds produced F_2 broods in what seem to be fairly good numbers per female involved. The F_2 brood has been exclusively male, but only 13 have been examined so far. The hybrids seem to be excellent for stocking in small ponds, provided contamination by other fish can be avoided. That is, their rate of reproduction is so slow that overcrowding does not occur, and growth is rapid throughout life. However, other fishes have appeared in all but one of the ponds stocked to date, the usual adventitious arrivals having been green sunfish and black bullheads. These fish very quickly crowd the pond and restrict first-year hybrid growth to as little as a third of an ounce.

INTRODUCTION

It is now well known that overpopulation is a serious problem in many ponds and small lakes devoted to rearing warm-water game fishes. Species such as the bluegill (*Lepomis macrochirus*) can reproduce so prolifically that the rate of growth of the resulting broods is slowed down to an extent which makes them slow to achieve even a minimum usable size, and may prevent their ever attaining any really satisfactory stature. Efforts to avoid or remedy such a situation have usually taken the form of stocking a fish-eating species like the large-mouth bass (*Huro salmoides*), to keep the numbers of the bluegills and similar species in check. Some success has been reported along those lines, and a considerable literature of the subject exists (Swingle and Smith, 1942; Bennett, 1943), but results have certainly not been uniformly satisfactory. An alternative procedure is based on the fact that hybrid sunfishes have been found to be infertile (Hubbs and Hubbs, 1933). If hybrids were to be used to stock a barren pond, and other fish were excluded, a rather close control of the population might be established. By restricting the number stocked it should even be possible to produce large fish much more rapidly than is usual in natural lakes or balanced ponds, since the inverse relationship between number and size extends up to rather rapid growth rates (Swingle and Smith, 1942). The idea that hybrid fish might be of practical value in situations of this sort has apparently occurred to

[1]This report is a part of the work of the Indiana Lake and Stream Survey, sponsored jointly by Indiana University and the Department of Conservation, Division of Fish and Game. Contribution Number 360 from the Departmnet of Zoology, Indiana University.

several investigators; it first reached the writer from Drs. D. H. Thompson and G. W. Bennett of the Illinois Natural History Survey. Nevertheless, it appears that, prior to the present attempt, no steps had been taken toward a practical trial—in part at least because it was considered impractical to keep native fish from contaminating the proposed ponds of hybrids.

In spite of the last-mentioned danger, it was decided that hybrids *might* be useful in many small Indiana waters, and our first pond of hybrids was reared at the Wawasee State Fish Hatchey in 1942, under the care of Superintendent Maurice Lung. The cross selected was between the bluegill (*Lepomis macrochirus*) and the redear sunfish (*L. microlophus*), our two largest and most valuable sunfishes. Male bluegills and female redears were put into a pond in early spring, and the resulting spawning was at least reasonably successful. The number of fingerlings obtained (46,000) was said, however, to be less than what is usually recovered from the reproduction of either of the parent species, by itself, in a similar pond. These fish were subsequently distributed into a number of waters. Nearly all of these plantings have shed light on one phase or another of the problem of production or utilization of hybrids. They will best be followed if presented in a numbered series, beginning with the original pond where the cross was made.

Results from Plantings of Hybrid Sunfish

1. *No. 22 Pond, Wawasee Hatchery.* Area—0.32 acre. This pond was stocked in April 1942 with 10-15 male bluegills and an equal number of female redears. There were apparently two principal spawning times, which produced fish of two size groups distinct enough to be followed through the season. Samples were taken as randomly as possible, and the fish were measured in millimeters to the fork of the tail and weighed in grams, as shown in Table 1.

The existence of two size groups made random sampling more than usually difficult; possibly a mean ratio of two small fingerlings to one large one would be approximately representative. The hybrids distributed on July 23, 1942, were taken from the larger group (mean weight, 0.56 gram); these fish are referred to subsequently as "Lot 1" hybrids. Similarly those distributed on October 20 seem to have been selected for size to a certain extent, to judge from the sample preserved, since the frequency distribution of the smaller ones was skewed and the average size abnormally large (*cf.* above). Their mean weight can be taken as about 1.5 grams, and they will be referred to as "Lot 2." The size of the average fish *in the pond* at this time was much less (only 0.47 gram—the quotient of the total weight of 18.2 kilograms by the total number counted, 39,000). Between October 20 and April 29 there was some growth (probably mostly in April).

The total production of the pond for the year was 46,000 fingerlings

TABLE 1.—*Length (to fork of tail) in millimeters and weight in grams of samples of hybrid (bluegill × redear) sunfish from Pond No. 22 at the Wawasee State Fish Hatchery.*

[See text for explanation of "smaller" and "larger" group.]

Date	Smaller group				Larger group				Combined average weight
		Length		Mean		Length		Mean	
	Number	Range	Mean	weight	Number	Range	Mean	weight	
July 6, 1942	35	13-17	15	0.06	141	22-27	24	0.26	....
July 21, 1942	95	17-25	21	0.14	53	27-33	31	0.56	0.29
Aug. 4, 1942	57	23-28	25	0.32	17	34-38	36	1.00	0.45
Aug 20, 1942	37	26-33	30	0.55	15	37-45	41	1.20	0.74
Sept. 9, 1942	62	28-35	31	0.55	23	38-45	41	1.13	0.71
Oct. 20, 1942[1]	48	28-40	36	0.76	101	41-57	47	1.96	1.58
Apr. 29, 1943	94	28-40	32	0.60	60	43-64	51	2.60	1.38

[1]The sample from the "Smaller group" on this date apparently selected for size.

weighing 48.7 pounds, or 152 pounds per acre (170 kilograms per hectare).

2. *No 27 Pond, Wawasee Hatchery.* Area—0.17 acre. The pond was stocked on April 29, 1943, with 1,500 hybrids. The sample taken at time of planting (Table 1) was evidently selected for size to some extent; their average weight can be taken as 1.4 grams.

The seining of the pond on October 14, 1943, yielded 743 of the original F_1 hybrids. All were measured, and their total weight taken. About a week later (October 20) the pond was drained and all the fish were removed. In addition to 558 additional F_1 hybrids, 11,500 fingerlings, presumably F_2 hybrids, and one largemouth bass, 253 millimeters long, were taken from the pond. Data on the three groups of fish are shown in Table 2. The two spawnings of the previous year could still be recognized in the length-frequency distribution of the F_1 brood, the two modes being at 80 and 110 millimeters when the fish were grouped by 5-millimeter intervals. The normal range of length was 75-100 for the smaller group, and 100 to 125 for the larger. Only four individuals exceeded 125 millimeters.

TABLE 2.—*Fork length in millimeters and weight in grams of all F_1 hybrid (bluegill × redear) sunfish and of samples of F_2 hybrids (?) from Pond No. 27 at the Wawasee State Fish Hatchery.*

Fish group and date of collection (1943)	Number	Mean length	Range of length	Standard deviation of length	Mean weight	Sex	
						Male	Female
F_1 hybrids (Oct. 14)	743	97	75-155	13.0	18.8	76	1
F_1 hybrids (Oct. 20)	558	....	....	....	15.2	....	....
F_2 hybrids(?) (Oct. 14)....	22	33	29-36	....	0.66	....	....
	2	22	22	....	....	....	....

The abundance of fingerlings came as a distinct shock, for while considerable nesting had been observed in the pond, other work with sunfish hybrids had suggested that the F_2 generation would be very scantily produced, if at all. For this reason we were at first inclined to blame a leakage of fry from other ponds, but the discovery of F_2's elsewhere has made their occurrence here seem more plausible. Besides, any leakage on the scale suggested would be a most exceptional occurrence at the Wawasee Hatchery. The point may be settled when an ichthyologist completes his study of the specimens, provided they are large enough to permit a definite determination. The two size classes of fingerlings were probably more nearly equal in numbers than the above sample suggests.

The total weight of F_1 hybrids removed from the pond was 50.3 pounds, as compared with 4.6 pounds when they were stocked. The net production therefore was 45.7 pounds, or 269 pounds per acre (302 kilograms per hectare). The weight of the largemouth bass and the fingerlings would increase this yield by possibly 50 pounds per acre.

3. *Lincoln City Pond, Lincoln State Forest.* Area—0.38 acre. A group of 10,000 hybrids was transferred to this pond on April 29, 1943. Their average size can be taken as about 0.7 gram.

The pond was drained November 16, 1943, and all fish recovered. Some other fish had entered the pond, including bluegills, white crappies (*Pomoxis annularis*), green sunfish (*Lepomis cyanellus*), common shiners (*Notropis cornutus*), bluntnose minnows (*Hyborhynchus notatus*), blackstripe topminnows (*Fundulus notatus*), black bullheads (*Ameiurus melas*) and largemouth bass (*Huro salmoides*). These fish, however, were mostly small and not very numerous—not more than 200 of all species together. There was only one largemouth bass, about 300 millimeters long. These unwanted species were separated from the hybrids without trouble, since the latter differed in size as well as color from the bluegills, the species most likely to cause confusion.

TABLE 3.—*Live weight in grams of all "standard" and "select" F_1 hybrids from the Lincoln City Pond, November 16, 1943.*
[See text for explanation of "standard" and "select"]

Fish group	Total number	Total weight	Average weight
"Standard" F_1 hybrids	4,882	16,640	3.41
"Select" F_1 hybrids	104	4,560	43.8
Total	4,986	21,200	4.25

TABLE 4.—*Fork length in millimeters, weight in grams, and sex ratio of samples of 50 "standard" and 50 "select" hybrids from the Lincoln City Pond.*
[See text for explanation of "standard" and "select"]

Fish group	Mean length	Range of length	Mean weight	Range of weight	Sex	
					Male	Female
Standard	60	55-67	3.62	....	49	1
Select	129	92-195	48.9	13-198	49	1

The hybrids were divided into two groups, "standard" and "select," whose weights are shown in Table 3. A sample of 50 hybrids of each sort was measured and weighed after preservation, as shown in Table 4. A larger sample of 253 "standard" hybrids was examined for sex (including the 50 above) and 6 females were found, or 2.4 percent. The "standard" fish from the Lincoln City Pond were used for stocking other ponds, and will be referred to as "Lot 3."

The total weight of hybrids taken from this pond was 46.8 pounds, compared to 15.4 pounds when stocked. The increase in weight was 31.4 pounds or 83 pounds per acre (93 kilograms per hectare). The loss of 51 percent of these hybrids during the summer is unexplained, and the net production of the pond is small.

4. *Bert Clark Pond, southeast of Vincennes, Knox County.* Estimated area—0.15 acre. This small pond is rather deep (up to 9 feet when full) and steep-walled, having been built in 1942 by scooping out a natural draw on a hillside. It is remote from other permanent water.

On October 20, 1942, 400 hybrids of Lot 2 (see Part 1 of this section) were planted. During the spring of 1943 the pond overflowed, and some fish may have escaped.

TABLE 5.—*Fork length in millimeters and weight in grams of F_1 and F_2 hybrids from the Bert Clark Pond, October 30, 1943.*

Fish group	Number	Mean length	Range of length	Mean weight	Range of weight
F_1 hybrids	3	156	151-160	97	87-104
F_2 hybrids	4	64	57-70	3.0	....

The pond was seined on October 30, 1943, with a 12-foot minnow seine, and data on the fish obtained are shown in Table 5. While only four seine hauls were made, it was clear that a relatively small number of F_2 hybrids was present; the same number of hauls in similar ponds stocked with native species would yield hundreds or even thousands of fingerlings. A single F_2 was saved and has been examined by Dr. Carl L. Hubbs, who reports as follows:

> The specimen is by no means as uniformly intermediate between the parental species as are the F_1 hybrids. . . . It is reasonably intermediate in some of the diagnostic characters, such as the stiffness and color of the opercular flap, the gill-rakers, and the length and sharpness of the pectoral fin. The pharyngeal arches and teeth are not as intermediate as might be expected, for in these respects this specimen is much closer to the bluegill than to the "shellcracker." The scales, however, are extremely large, large even for the western form of *L. microlophus* (I count only 35 in the lateral line). Apparently there is some degree of Mendelian segregation in the F_2.

The pond was seined October 23, 1944, using a 30-foot minnow seine, and both the original F_1 hybrids and some younger fish were taken (Table 6). At the time this seining was done it was assumed that the 11 smaller fish were of the F_2 stock hatched in 1943. Examination of their scales showed, however, that all were fish of the year, that is, hybrids hatched in 1944. These fish were in all likelihood F_2 hybrids, because none of the 1943-hatched F_2 stock turned up then, or subsequently. (If some of the latter were still present, they could have spawned in 1944 and produced F_3 hybrids or a back-cross of F_2 on F_1.) The fish seined are currently being studied by a well-known systematist.

TABLE 6.—*Fork length in millimeters and weight in grams of F_1 and F_2 hybrids from the Bert Clark Pond, October 23, 1944.*

Fish group	Number	Mean length	Range of length	Mean weight	Range of weight	Sex
F_1 hybrids	2	202	201-202	218	212-223	....
F_2 hybrids	11	99	79-114	25.5	11-42	All male

The pond was seined again with a 30-foot seine on October 17, 1945. In four hauls one male fish was taken; it was one of the original F_1 hybrids. Measured fresh, it was 238 millimeters long and weighed 435 grams. Its scales showed three distinct annuli, and in successive years its size was calculated as 33, 147, and 209 millimeters.

Seining yielded two more male F_1 hybrids on April 18, 1946: one

237 millimeters long and weighing 455 grams, and one 248 millimeters long and weighing 467 grams. Their ages were confirmed by scale reading.

Two male fish of the 1944 hatch were taken by seining on June 17, 1946; these fish were of the same brood as the F_2 hybrids taken October 23, 1944. Their observed and calculated size, in millimeters, was as follows:

Length at capture	*Calculated length at end of*	
	1944	*1945*
189	92	176
204	109	190

The big fish had by this time attracted considerable attention, and throughout the summer of 1946 several anglers fished the pond. Hybrids even larger than the 16- and 17-ounce specimens of April were reported caught.

5. *Pigg Pond, south of Sullivan, Sullivan County.* Estimated area —1.2 acres. This pond was built in 1943 by means of a gin pole and drag line, deepening a rather broad natural draw and piling the dirt into a dam at the foot. When the fish were planted, it was not more than a fifth filled, but the winter and spring rains made it overflow early in 1944. The pond was stocked November 17, 1943, with 1,000 hybrids from Lot 3 (see Part 3 of this section), weighing 7.4 pounds.

Seining the pond on October 23, 1944, yielded six F_1 hybrids (Table 7), *i.e.,* the stock which was planted, and no other fish. The increase in average weight from time of stocking was 103 grams, or 3½ ounces, in one growing season. The one specimen preserved was a male.

TABLE 7.—*Fork length in millimeters and weight in grams of a sample of the F_1 hybrids from the Pigg Pond, October 23, 1944.*

Number	Mean length	Range of length	Mean weight	Range of weight
6	164	159-174	106	97-126

Two hauls with the 30-foot seine on November 14, 1945, yielded one F_1 hybrid of 185 millimeters and 184 grams, and numerous green sunfish. It was learned that a number of hybrids of about the same size as the specimen taken had been caught recently from the pond. The sunfish were entirely fish of the year.

6. *Croddy Pond, west of Kent, Jefferson County.* Estimated area —4 acres. Built in 1942, this pond receives water from a considerable watershed—possibly 100 acres. At the time the first fish were put in, the pond was perhaps a third full (area, *ca.* 1.5 acres) and it filled entirely the following winter. The pond was stocked with 1,300 Lot 1 hybrids (see Part 1 of this section) on July 23, 1942, and on October 20, 1942, 7,700 Lot 2 hybrids were planted.

When the pond was seined on July 7, 1943, numerous hybrids were

taken, among which the two lots named above could still be sharply distinguished as to size (Table 8). In addition a number of black bullheads were taken.

TABLE 8.—*Fork length in millimeters, weight in grams, and sex ratio of fish in a sample taken from the Croddy Pond, July 7, 1943.*
[See Part 1 of this section for description of Lots 1 and 2]

Fish group	Number	Mean length	Range of length	Mean weight	Range of weight	Sex	
						Male	Female
F_1 hybrids of Lot 1	12	121	107-135	49	28-71	3	0
F_1 hybrids of Lot 2	29	29	61-82	6.7	5-13	28	1
Black bullheads	6	131	115-145	40	23-59	....	....

The presence of black bullheads in the pond is unexplained. Apparently a few adults were present and spawned in 1942, producing the brood which has been taken subsequently. Their presence however did not prevent the hybrids' making good growth, especially in 1942 before the Lot 2 hybrids were planted. The Lot 1 fish grew from an average weight of 0.6 gram in late July 1942 to 49 grams in early July 1943. Fishing of the pond started June 16, 1943, and several hundred hybrids were taken that summer, as well as a considerable number of bullheads.

The pond was again seined in July 1945 when the principal catch was a tremendous number of small green sunfish. A few hybrids were taken, 150-175 millimeters long, and local information was that this was the principal range of sizes being caught by fishermen. Small bullheads also were being caught.

7. *Adams, Westphal, or Root Pond, Knox County.* Estimated area —0.8 acre. This partly shaded pond is situated in a draw on a hillside, a half-mile from an intermittent stream. A leak in the dam in 1943 made its actual level fall, so that it was only a third of its spillway area at the end of summer. On October 14, 1942, 1,200 hybrids of Lot 2 were planted.

TABLE 9.—*Fork length in millimeters and weight in grams of a sample of fish taken from the Adams Pond, October 30, 1943.*

Fish group	Number	Mean length	Range of length	Mean weight
F_1 hybrids	6	113	93-140	30
Green sunfish	12	50	38-65	1.9

The pond was seined October 30, 1943, at which time were obtained 6 hybrids and possibly 500 green sunfish, as shown in Table 9. The hybrids had apparently made considerable growth before a numerous brood of young green sunfish began to compete with them.

8. *Thorne Pond, Knox County.* Estimated area—1.5 acres. A few small water holes, which may well have held a few fish, existed in the ravine in which this pond was built in 1942. In early summer of 1943 much of the water was drained from the pond to water stock, and on October 30 it was about a fifteenth of the spillway area and not more than 2 feet deep.

On October 14, 1942, 2,300 hybrids of Lot 2 were planted. Seining of the pond on October 30, 1943, yielded 22 hybrids and 300 green sunfish in one haul, as described in Table 10. All the green sunfish appeared to be age-group 0. In the face of this competition, the hybrids had made only fair growth, increasing 27 grams during the season, on the average.

TABLE 10.—*Fork length in millimeters and weight in grams of sample of fish taken from the Thorne Pond, October 30, 1943.*

Fish group	Number	Mean length	Range of length	Mean weight	Range of weight
F_1 hybrids	22	112	103-128	27.5	22-46
Green sunfish	40	65	53-76	4.6	....

9. *Coulson Pond, Sullivan County.* Estimated area—2 acres. This pond was built in 1940, and had never been stocked. However its dam is low, and it drains a sufficient area that in rainy season a creek sufficient to attract fish flows from it. On November 17, 1943, 1,000 hybrids of Lot 3 were planted.

TABLE 11.—*Fork length in millimeters, weight in grams, and sex ratio of a sample of fish taken from the Coulson Pond, October 24, 1944.*

Fish group	Number	Mean length	Range of length	Mean weight	Range of weight	Sex
F_1 hybrids	7	89	83-92	14.3	12-16	All male
Green sunfish	27	68	35-91	7.4	1-15	....
Black bullheads	7	136	107-165	35.6	16-60	....
Golden shiners	18	100	90-106	15.8	11-23	....

Seining on October 24, 1944, resulted in the capture of seven hybrids and a large number of three other species (data on samples in Table 11). There was also a much less numerous group of smaller golden shiners (*Notemigonus crysoleucas*), not included in Table 11, which was represented in the sample by one specimen of 70 millimeters length and 5 grams weight. The green sunfish included age-groups O and I, whose size ranges overlapped broadly.

10. *Sweet Gum Pond, near Dupont, Jefferson County.* Estimated area—0.8 acre. This pond, built in 1941, is quite shallow—not over 3 feet. Some junior fishermen of the neighborhood were said to have stocked it with bullheads and "perch" from a nearby creek. A planting of 1,300 Lot 1 hybrids was made on July 23, 1942.

TABLE 12.—*Fork length in millimeters, weight in grams, and sex ratio of a sample of fish taken from Sweet Gum Pond, July 7, 1943.*

Fish groups	Number	Mean length	Range of length	Mean weight	Range of weight	Sex
F_1 hybrids	6	69	59-79	7.8	5-12	All male
Green sunfish	31	53	43-100	3.6	up to 20	....
Black bullheads	8	81	70-91	9.1	6-14	....
Fathead minnows ..	5	54	45-62	4.0	3-6	....

The pond was seined July 7, 1943, at which time six hybrids, numerous green sunfish and fathead minnows (*Pimephales promelas*), and a fair number of black bullheads were obtained. The hybrids and

a sample of the others were measured, as shown in Table 12. All of the native fish in the pond seemed to be of the 1942 spawning. A number of the green sunfish scales were examined, including the largest and smallest individuals, and all were age-group I. The bullheads also are obviously age-group I. There was one additional fish of age-group O preserved; this fish was 34 millimeters long.

11. *Springer Pond, Sullivan County.* Estimated area—1.5 acres. The pond was built in 1941, in a rather steep-walled valley. It had not been stocked, officially at least. On November 17, 1943, 1,000 hybrids of Lot 3 were planted.

No hybrids were taken in four seine hauls made on October 24, 1944. There were possibly 600 age-group O green sunfish (30-55 millimeters), a fair number of age-group I (about 12 in the sample; 60-118 millimeters), and one member of age-group II (128 millimeters). Four O-group bluegills (40-45 millimeters) were also taken and one largemouth bass (70 millimeters). All these fish were taken under conditions unfavorable for seining; doubtless more intensive effort would have located a few hybrids.

12. *Willow Pond, near Dupont, Jefferson County.* Estimated area—0.7 acre. This pond was built in 1941, and was not known to contain other fish when hybrids were planted. Five hundred hybrids of Lot 1 and 100 fingerling largemouth bass averaging about 70 millimeters in length were stocked July 23, 1942.

TABLE 13.—*Fork length in millimeters, weight in grams, and sex ratio of a sample of fish from Willow Pond, July 7, 1943.*

Fish groups	Number	Mean length	Range of length	Mean weight	Range of weight	Sex
F_1 hybrids	3	78	62-87	11.7	5-16	All male
Bluegills	16	54	38-78	3.1	3-10	....
Largemouth bass	1	250	....	....	....	....

Seining on July 7, 1943, yielded the fish for which data are given in Table 13. This pond was meant to test the effect of planting hybrids and largemouth bass, without other species. However, it already contained a brood of bluegills spawned in 1941, and these fish now dominate the fish population. The largemouth bass taken was so large as to suggest that it too may have been in the pond prior to our stocking it, though that is not necessarily true. Unfortunately it escaped before scales could be taken.

Usefulness of Hybrids for Stocking Ponds

Two characteristics of the hybrids obtained are of special interest, and both have practical importance. An unbalanced sex ratio is normal among sunfish hybrids, but Hubbs and Hubbs (1933) did not report for any cross as small a percentage of females as found here, except in very small samples. The total number of F_1 bluegill $\times$ redear hybrids examined for sex has been 428, of which 9 or 2.1 percent were

females. The possible limits of error of this figure, for 95 percent confidence, are 0.9 to 4.0 percent. Among the Lincoln City "standard" fish, the average length of 6 females was 56.7 millimeters, and of 49 males was 60.5 millimeters—a significant difference ($t = 3.57$ for $n = 53$). The other females found bear out this tendency toward smaller size. The single female from the Lincoln City "selects," for example, was 110 millimeters, whereas the average of 49 males was 129 millimeters. Another noteworthy point is that the 13 F_2 (F_3?) hybrids taken from the Clark Pond in 1944 and 1946 were all males, suggesting that an abnormal sex ratio continues to appear in generations beyond the first hybrid one.

The second important point is a more unexpected one: namely, that the F_1 hybrids can produce offspring. They have been found now in two ponds—Pond 27 at Wawasee Hatchery and the Clark Pond. In the first-named pond, the 11,500 fry obtained represent a reasonably good production, considering the circumstances. If the 1,500 fish put in the pond were 2 percent female, there would be 30 females. Of these, however, the two-thirds or so belonging to the "small" group were probably too small to spawn in 1943, as they were only 75-100 millimeters long even at the close of summer. The eggs actually laid then were evidently produced by a very limited group of spawners. Allowing for considerable consumption of fry by the F_1 hybrids and by the stray largemouth bass (which grew from a fingerling to 10 inches long), it is evident that several of the females must have produced a fairly large number of fertile eggs. A somewhat similar story can be told of the Clark Pond. The 400 F_1 hybrids planted probably included about 8 females, and since the pond is strictly mud-bottomed, the success of spawning by any sunfish would not be expected to be especially great. The number of fingerlings produced is of course unknown but it was probably rather small, as only four were taken in four hauls with a 12-foot seine in 1943. Another spawning, either of F_1 or F_2 fish, occurred in the Clark Pond in 1944. However, in the Pigg Pond, where the F_1 hybrids had no competition from other fish during the first year, no trace of fingerlings was found either in the autumn of 1944 or in 1945.

From the standpoint of the original purpose of the experiment, the picture presented is this. The F_1 hybrids are overwhelmingly male—about 49 in 50. Such females as do occur can produce eggs which, when fertilized by F_1 males, produce fry in at least reasonably large numbers. However, all of the (rather small) number of F_2 fish examined so far have been males, and, whether because of the scarcity of females or for other reasons, no sign of the abundant reproduction characteristic of non-hybrid bluegills and redears has yet appeared among hybrid progeny. When hybrid fingerlings are stocked at the rate of up to 2,500 per acre, the net rate of reproduction in the first few years has not been such as to cause overcrowding, and hence the original purpose of using hybrids has not been defeated. Indeed, the

growth of the F_1 hybrids in the Bert Clark Pond has considerably exceeded any rates of growth which have been observed among native fish, either bluegill or redear, in any of the Indiana waters studied to date. Although the relatively sparse population present in the pond is probably the principal factor responsible for this rapid growth, some effect of hybrid vigor may also exist.

In some ways a limited amount of reproduction of hybrids is preferable to complete sterility. However, the data so far are not sufficient to indicate whether a hybrid stock will maintain itself; periodic replenishing, therefore, may prove necessary.

Experience to date can scarcely be said to indicate that hybrids will prove *generally* useful for stocking ponds. The difficult problem is that of avoiding contamination of the pond with native fish. The total number of ponds listed above is nine, excluding the hatchery ponds. Only one of these completely escaped contamination (for a period of 3 years). The effect of the presence of other fish is shown in Table 14. The average first-year weight increase of hybrids was about 100 grams in two uncontaminated ponds. In three ponds where the contaminating species first appeared in numbers during the hybrids' first growing season, the hybrids' increase of weight in the first year varied from 26 to possibly 55 grams. In three ponds which contained large populations of other fish from the time the hybrids were planted, their first-year's growth was only about 8-12 grams.

TABLE 14.—*Average increase in weight of hybrids during their first year in the pond, in relation to presence of other fishes.*
[For ponds marked with an asterisk, the growth is 2 summer weeks short of a full growing season]

Pond	Fishes present, in addition to hybrid sunfish	Weight increase of hybrids (grams)
Clark	None	95
Pigg	None	103
Croddy*	Black bullheads	48
Adams	Green sunfish	28
Thorne	Green sunfish	26
Coulson	Green sunfish Black bullheads Golden shiners	11
Sweet Gum*	Green sunfish Black bullheads Fathead minnows	7
Willow*	Chiefly bluegills	11

One success out of nine trials is certainly not an encouraging score, but, viewed in that manner, the picture is somewhat too gloomy. Of the ponds mentioned, one was known to contain other fishes before the hybrids were stocked and one at least had a few water-holes in its basin which could have contained fish, and apparently did. One or two additional ponds had outlets which could readily permit the entrance of fishes during the high water. Excluding all these, there remain four contaminated ponds whose beds are said to have been "bone dry" and whose outlets do not seem likely to have constituted an avenue of entrance for fish—though it is impossible to be certain on this last point. What the source of the contamination will prove to

be is unknown. Transportation of eggs on the bills or feathers of birds should perhaps be considered. It is easy to postulate a secret transplantation of fish by misguided amateur fishermen, but the predominance of green sunfish and to a less extent black bullheads, among the new arrivals, makes clandestine stocking less likely than it might seem. That is, there are other more valuable species which would be more likely to be introduced.

Whatever their origin, the two species which predominate among these adventitious arrivals are particularly undesirable ones. The green sunfish only infrequently become large enough for catching, and the black bullhead similarly is our slowest-growing species of *Ameiurus*. Of the two, the bullhead is apparently the less undesirable, at least during the early life of a pond.

For the present, then, it would seem wise to try to stock with hybrids only when the pond in question is small, has a steep outlet, and is remote from other water. If the pond could and would readily be drained or treated with poison, in the event of contamination, greater chances might be taken with the above requirements. A possible alternative would be to stock largemouth bass fingerlings after giving the hybrids a chance to attain some growth, as a sort of insurance against possible contamination. It may even prove worth while to build small ponds with overhanging spillways. In that event, if transportation of fish by birds or mammals can be ruled out, it should prove quite practical to maintain hybrids in ponds close to other waters.

Acknowledgments

Many individuals have assisted in the project just described. Mr. John Gottschalk, formerly Supervisor of Fisheries for Indiana, helped to plan the experiment and authorized the original production of hybrids at the Wawasee Hatchery in 1942. Since that time the work has enjoyed the continued support of officials of the Division of Fish and Game. Several employees of the Soil Conservation Service, of whom Messrs. Lester H. Binnie and J. G. Zimmerman may be mentioned particularly, have helped by locating ponds suitable for the experiment; and the former Regional Biologist of the Service, Mr. Warren W. Chase, has given the project his wholehearted support. All of the gentlemen just mentioned have assisted in seining and other field work at various times, as have Messrs. Donald C. Scott, Louis A. Krumholz, and others.

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THE DESIGN AND OPERATION OF A TRAP FOR THE CAPTURE OF MIGRATING YOUNG SOCKEYE SALMON

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Abstract

A means of obtaining young sockeye salmon, *Oncorhynchus nerka,* during their seaward migration by use of a netting fence and a central trap has been found successful in the Lakelse River, British Columbia. By operating at the point of maximum width and minimum rate of flow, the problems of current force and accumulation of debris were overcome. Increased rate of flow into the trap, which served to attract the fish, was obtained by use of a funnel entrance. It was discovered that the size of the openings of the trap must be such as to allow the entrance of schools of sockeye rather than individuals. These schools were found to converge and enter the trap more readily through slits in a horizontal plane than through those in a vertical position.

Introduction

In 1944 a 5-year investigation was undertaken by the Fisheries Research Board of Canada to determine whether there was a true decline in the salmon population of the Skeena River, British Columbia. If there was such decline in any species, efforts were to be directed toward determining the cause and to formulating recommendations for remedial measures. In the succeeding study of both the biological and commercial aspects of the fishery, sockeye salmon, *Oncorhynchus nerka,* have received most attention since this species is of major economic interest. It can now be demonstrated for the sockeye that a continued and unquestionable decline has occurred in the catch over the past 30 years.

As a part of the investigation, life-history studies were of paramount importance in laying the foundations for an understanding of the interrelations of survival and mortality, distribution, and possible segregation of runs with respect to habits, and migration times. For sockeye, the adults are known to spawn usually in streams which are tributary to lakes rather than in the rivers below them. The alevins emerge from the gravel beds in the early spring and move down as fry into the lake where they spend one or more years prior to migrating seaward. The majority return from the ocean in their fourth and fifth years.

To ascertain the extent to which the fish wander in the ocean and to what degree they return to the original source, it was desirable to obtain yearling migrants in numbers to be marked by clipping a given combination of fins to render them identifiable at later stages. Furthermore, a complete count of the young leaving the lake was a necessary requisite for an assessment of the losses which occurred between egg deposition and time of migration.

This general type of investigation has been conducted elsewhere, at Cultus Lake, B. C. (Foerster, 1929), at McClinton Creek, B. C. (Pritchard, 1939 and 1944), and in south-eastern Alaska (Davidson, 1934). Operations such as these invariably involve a fence completely blocking the outlet river and incorporating a trap system which permits ready capture and handling of the young salmon.

Each locality presents its own problems in selecting a fence site and overcoming the difficulties introduced by current rates, river bottom, flooding, and accumulated debris. A rather inexpensive technique involving comparatively little work and experience was designed in the spring of 1946 to answer the demands in the Lakelse Lake area of the Skeena drainage.

Acknowledgments

The Skeena River investigation is under the direction of Dr. A. L. Pritchard. His encouragement and cooperation in procuring the material as well as in criticizing and making suggestions for the design of the structure, have done much to make the operation a success.

Location and Description of Lakelse River

Lakelse River which drains Lakelse Lake (54°23′ N. Lat., 128°33′ W. Long.) runs in a north-westerly direction for 12 miles to join the Skeena River at a point some 70 miles due west from the coast. Immediately below the lake the river has a maximum depth of 24 feet; the depth then decreases fairly abruptly as the river expands into a sweeping arm over the next half-mile of its course. At the center of this arm the depth averages 4 feet, with a maximum width of 800 feet and a current strength of not more than one-quarter mile per hour. One-half mile further down the character of the river changes to a fast-flowing (4-6 miles per hour in spring), comparatively narrow (100-150 feet), turbulent stream. Efforts to obtain migrants in this lower section during 1944 and 1945 were fruitless and only went to prove that a major engineering project would be necessary to overcome the difficulties, particularly those imposed by current strength. In 1946 it was decided to move upriver and into slower water despite the great width and log-strewn shore line which had made all previous attempts impracticable.

Design and Construction of Fence and Trap

To span and block the river at its widest point, two lengths of seine netting were purchased, each 500 feet long and of ½-inch stretched mesh. The lead and cork lines were of ¼-inch manila rope, the actual leads and corks being left off. These "arms" were inserted in the river, sweeping downstream out from the banks in a wide **V** to a central trap (Fig. 1). The netting was held in place by attaching it at 15-foot intervals to a guy rope (½-inch manila) by secondary lines which extended at each point of attachment out from the cork

line to the main guy. The cork and lead lines were separated by 8-foot stakes which held the cork line well above the surface and the lead line tight on the soft mud bottom, even depressing it some inches below this level. The force imposed on the netting by the current was thus resisted through the action and strength of the main guy and the resistance of the retaining stakes driven into the river bottom. By using a large area of netting (8,000 square feet) in such a slow

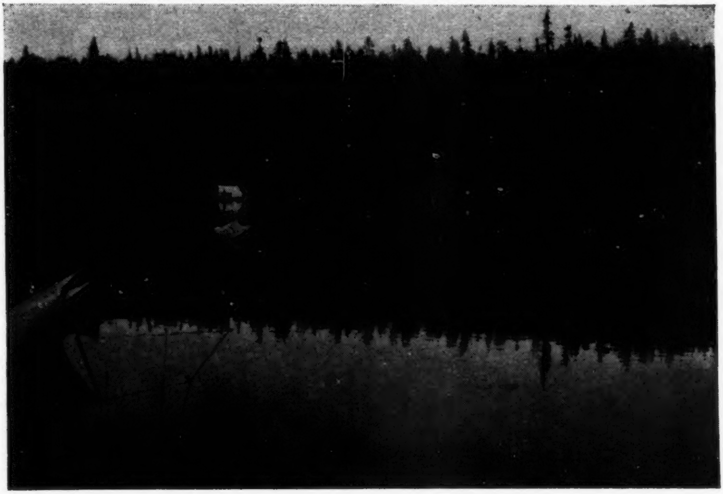

FIGURE 1.—The "netting fence" seen from the southwest bank of the river. The white tent on the float marks the position of the central trap; the two white flags with a sign-board between them indicate the boat passage over the far arm of the netting.

current the accumulation of debris was at no time a serious hazard and did not necessitate cleaning more often than once in 3 days, usually once in 5 days.

The trap (Fig. 2) was built of two sections, bolted together after each had been floated into place and sunk to the bottom. The first section was a large funnel entrance, joined directly to the two arms of netting, with an opening 12 feet wide and 6 feet deep which narrowed down to two separate openings 2 feet wide leading directly into the second section by adjustable doors. This whole structure was of tightly fitted planks and introduced for the express purpose of creating a current into the second portion which served to attract the fish and had a tendency to sweep them into the trap.

The second portion consisted of four pens, each 8 feet square and 6 feet deep, forming a complete 16-foot square, with the front two opening into the second two by a pair of double doors similar in design to those leading from the funnel entrance. For a single pen the doors could be adjusted either to close or to form a slit-like entrance operating in the fashion of the funnelled entrances of a minnow trap or fyke net. The increased current and volume of water passing through the entrance was made possible by building the walls of the trap of frame-work over which was stretched fine-meshed seine netting. The water passing through the doors into the trap was then free to disperse out through the mesh openings of netting with a surface area equivalent to 336 square feet.

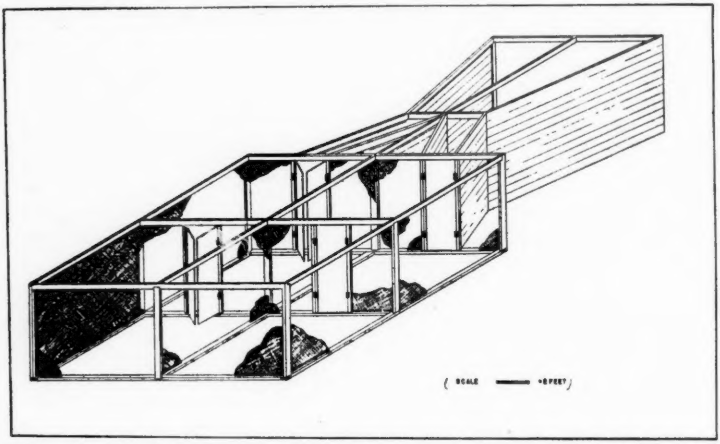

FIGURE 2.—Drawing of trap used for the capture of young migratory salmon.

To remove the captured fish once they had entered the trap, each pen had a false bottom lifted by means of a pulley system attached to a high scaffolding over the whole structure. The false bottoms were like large dip-nets each made of an outer framework very slightly smaller than the inner dimensions of the pen. A tight seal to the netting walls was maintained by a flap of folded canvas overlapping the entire edge of the frame. At times there were thousands of young salmon in a single quadrant. In the course of removing these fish, the false bottom could be raised in stages until the whole structure was out of water and the last fish captured.

OPERATION OF THE TRAP

By using a double entrance into the trap from the single opening of the funnel entrance one side or the other could be emptied of fish

without closing off the entire system. After the doors were closed on one side, the migrants, mainly sockeye but also including coho salmon, *O. kisutch,* and a few spring salmon, *O. tshawytscha,* were concentrated at the surface by elevating the false bottoms. From this position they were brailed out and weighed in water; a running sample of at least 20 percent was set aside in floating traps for enumeration and calculation of the total daily run. At the same time marking of the yearling sockeye was carried out by clipping both pelvic fins. In expert hands this latter operation can be accomplished at the rate of 800 per hour.

For convenience in performing the various operations in mid-river, catwalks were built around and over the trap and a float 20 feet by 16 feet moored alongside. A tent, marking-trough, recording table, and weighing stand were erected. Each of these is illustrated in Figure 3. On the left of the float may be seen two men sitting at the marking trough, while on the right, fish are being emptied into a bucket for weighing and liberation. Between these two is the recording table. Immediately downstream from the float, in the foreground of the picture, are two floating traps, one from which the markers obtain their fish and one which contains the sample of weighed sockeye. On the trap itself are two men, one kneeling to close off the entrance doors prior to raising the false bottom of the first pen, and the other leaning over to lower the false bottoms of the right-hand side of the trap to bring that half into operation.

Discussion of Improvements

To observe simplicity of description some of the refinements which were introduced during the course of operation were omitted from the section on "design." These changes were the result of experience and observations on the movements of young sockeye and their reaction to such an obstacle. It soon became apparent that the size of an individual fish was not the critical factor to consider in making the adjustments of the openings. Only a very few migrants would enter through a vertical slit of 2-inch diameter and 5-foot height. The entrance had to be of sufficient size to permit a school to enter *en masse,* for single fish would not break away to lead the rest through the opening. The circumstances within the trap were almost the reverse, for, once inside and no longer free to move further downstream, the fish became dispersed and sought liberation in every direction, particularly in an upstream course. Their success in locating the narrow outlet and point of maximum current was almost phenomenal. Within a very short time one or more fish were on their way out, leading the rest in a long stream, and, like sheep, the oncoming schools were swung back out of the funnel entrance. Very soon the whole trap became singularly empty. Once this exit upstream had ceased, leaving a few stragglers behind, the whole cycle commenced again, but never to a degree that absorbed the mounting

numbers of fish above the trap and netting block. This fact was very apparent at the start of a day's operations. During the peak of the migration, although the trap had been left all night with the doors properly adjusted, in the morning there was only a relative handful in the pens, while above the structure thousands of yearlings could be observed. Manual operation of the doors was immediately put into practice. They were swung wide open; an increased volume of water poured through; a multitude of fish streamed in and, if the entrapped fish endeavouring to escape were turned back, the influx continued unabated. By alternately closing off one side of the trap or the other, thousands of migrants could be passed through (89,128 sockeye on May 23, 1946) and the mounting numbers handled.

FIGURE 3.—A view of the central trap from downstream illustrating the different operations.

The answer to the mechanical problem of operation is either to create such a strength of flow through the openings that the fish cannot swim against it (*e.g.*, a small waterfall over a lip), or to introduce false currents greater than those in the entrance which direct the fish away from the true inlet. A solution was obtained near the end of the program by leaving the doors wide open and introducing an entirely new "lead." This lead consisted of a framework covered by netting with a wide opening converging in the horizontal plane from above and below, like a **V** tipped sideways, to a slit 3 inches

wide and extending well past the center of a pen. The incoming fish showed no reluctance to fan out and converge in the horizontal plane as they had done in the vertical phase. Since the whole current of water was passing through netting in which there was only a small area of sufficient size to permit exit (the horizontal openings) the efficiency of capture verged on 100 percent. This arrangement was found to operate extremely well at night time.

Results from the Operation of the Trap

The run commenced to trickle through early in May, built up rapidly in the third week and reached a peak by the 23rd of that month. At the end of the first week in June it was apparent that the migration had reached its final stage; it declined from that time on to a relatively insignificant number on June 20 when operations were terminated. The entire number of sockeye which had been handled totalled 557,400. These fish, being almost completely of one age group, were the result of a parent seeding in 1944. Calculations on the basis of the most reliable data available indicate that the mortality from egg deposition to the migrant stage was almost 99 percent.

During the migration and distributed throughout the main body of the run, 100,967 yearlings were marked by clipping both pelvic fins. Appreciable returns cannot be expected from these fish until the years of 1948 and 1949.

By incorporating the more efficient "leads" into the pens, it should now be possible to obtain a picture of the trends and fluctuations of the migration without serious distortion of the information such as might result from placing an obstacle in the path of migrants. These natural variations may then be correlated with changes in the physical and chemical features of the river and lake, or even further back with the meteorological phenomena in an effort to discover the conditions which are most closely related to the activities of the fish.

Summary

Life-history studies of young salmon, particularly sockeye, have been instituted on the Lakelse River, B. C., by the use of a trap.

An inexpensive means of obtaining these fish incorporating a netting fence and a central trap has been found successful. The limitations and problems involved are mainly those concerned with current strength, first in relation to the installation of the river block, and second in relation to directing fish into the trap, yet not permitting their escape. By operating in a position with slow rate of flow many of the engineering problems were overcome, while by funnelling the flow into the trap, a directive force influencing the fish to enter was produced.

Young sockeye salmon move in schools and can only be induced to enter a trap which admits them as a group rather than as individuals.

The schools of young sockeye were found to converge in a horizontal plane more readily than in a vertical plane. By introducing horizontally converging leads the degree of escape out of the trap was made minimal. With increased efficiency of capture interference in the trends of the natural migration were reduced.

A total of 557,400 young sockeye were handled, the migration extending from early May to mid-June and reaching a peak on May 23. The mortality between egg deposition and migrant stage was calculated as close to 99 percent.

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A GYRODACTYLOID PARASITE FROM THE URETERS OF LARGEMOUTH BASS AT THE JONKERSHOEK INLAND FISH HATCHERY, SOUTH AFRICA

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Abstract

Heavy losses of largemouth bass fingerlings at the Jonkershoek Inland Fish Hatchery, Stellenbosch, South Africa, were attributed to heavy infestation of the ureters with a gyrodactyloid parasite closely related to *Acolpenteron ureterocoetes*. The parasite has no intermediate host, and in heavily infested fish may complete its entire life cycle in the ureters. Infected fish display inflammation of the kidneys, ureters, and urinary openings and, in acute cases, great abdominal distension anterior to the cloaca. Some diseased fish die gradually, others in convulsive spasms. This disease occurs only in fish reared on artificial food in concrete rearing tanks. The spread of the disease can be checked by transferring fish from such small tanks to fertilized open ponds, where natural food and absence of crowding usually alleviate the condition. It is recommended that largemouth bass be reared to the fingerling stage in fertilized earthen ponds 0.1 acre or more in size, stocked at the rate of 12,000 advanced fry per acre and drained after about two months, when a survival of 80 percent or more may be expected.

During the months December 1943—March 1944, great losses occurred among largemouth bass fingerlings which were being reared in concrete tanks at the Jonkershoek Inland Fish Hatchery, Stellenbosch. Examination of the fish revealed that their ureters were heavily infested with a small trematode belonging to the family Calceostomatidae (superfamily Gyrodactyloidea).

Description of parasite.—This small white trematode, which attains a length of 0.8 millimeter, lives attached to the walls of the ureters and the urinary bladder by means of a cup-shaped haptor armed with 14 marginal hooklets. Eye-spots are present in the larvae and juveniles but these break up into a number of scattered black pigment spots in the adults. This parasite would appear to be closely related to *Acolpenteron ureterocoetes*, described by Fischthal and Allison (1941) from the ureters of wild largemouth and smallmouth bass from Michigan. It differs from *A. ureterocoetes* in a few respects of which the absence of Mehlis' gland and of sensory hairs are the most clearly marked. For further details of the structure the reader is referred to Figure 1.

One yellowish brown egg, possessing a short anopercular process, is laid at a time, and passes out with the urine. By keeping a largemouth fingerling in a glass funnel of which the outlet was corked, 85 eggs were recovered from the bottom of the funnel after 24 hours. Eggs obtained in this way hatched in 14-60 days, depending upon the temperature.

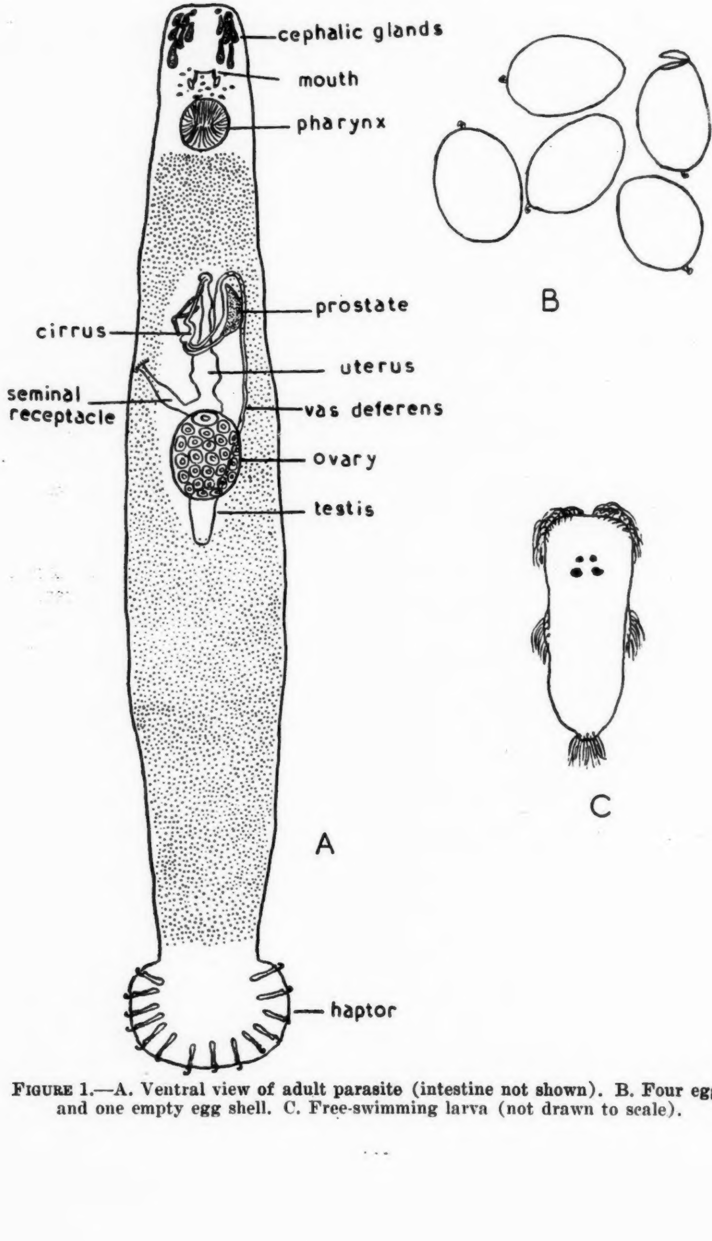

Figure 1.—A. Ventral view of adult parasite (intestine not shown). B. Four eggs and one empty egg shell. C. Free-swimming larva (not drawn to scale).

The larvae has two pairs of eye spots and swims with a spiral clockwise motion. Movement is effected by means of cilia situated around the head end, on the sides at the middle, and on a posterior prominence situated dorsal to the haptor (Fig. 1C). There is no intermediate host and the free-swimming larva attaches itself to a fish, throws off its cilia and starts life as a parasite. In heavily infested fish, however, the whole life cycle may be completed within the ureters as will be described later.

Symptoms.—The first external sign of infestation is that the urinary opening is red and inflamed. When the fish is held against the light the inflamed kidneys and ureters are visible as a red line running below the spinal column, and bending downwards to end in the urinary opening. In cases of acute infestation the belly becomes extremely swollen in the region immediately anterior to the cloaca.

Some diseased fish gradually become weaker and sink to the bottom where they die. Others, apparently healthy, execute a mad leap through the water, and die with gills and mouth distended, and the body rigid and arched backwards. This occurs when the fish are disturbed, as by netting.

Many dying fish exhibit a characteristic light-colored area around the base of the dorsal fin; this area coincides with the position of the kidney and is undoubtedly caused by the diseased condition of this organ.

In cases of slight infestation the host does not appear to suffer; as the disease advances, however, the ureters become blocked by the swelling of their walls. Consequently the passage of urine becomes difficult and is probably prevented altogether. The anterior portions of the ureters swell out into irregular structures (Fig. 2) with tightly stretched transparent walls, and filled with urine in which masses of yellow eggs in all stages of development, and often mixed with white crystals precipitated from the urine, can be seen. The eggs may even hatch in the ureter, as is often proved by the presence of empty egg shells, free-swimming larvae, and young parasites.

The posterior sections of the kidneys are also greatly swollen but in the advanced stages of the disease only an anaemic mass of degenerated tissue is left, which could hardly be capable of performing any excretory function.

Although this parasite has been found in all three species of bass cultured at the Jonkershoek Hatchery, spotted bass are relatively free from infection; largemouth bass, which are the most susceptible, show heavy infections only when reared in concrete tanks or in small earthen rearing ponds. This is no doubt due to the crowded conditions which facilitate the spread of the parasites. The fact that largemouth bass are more sensitive to artificial rearing than smallmouth or spotted bass may also have some bearing on their susceptibility to this disease.

The problem faced at this hatchery is that when bass have reached the desired size in early summer, the high temperature of the water

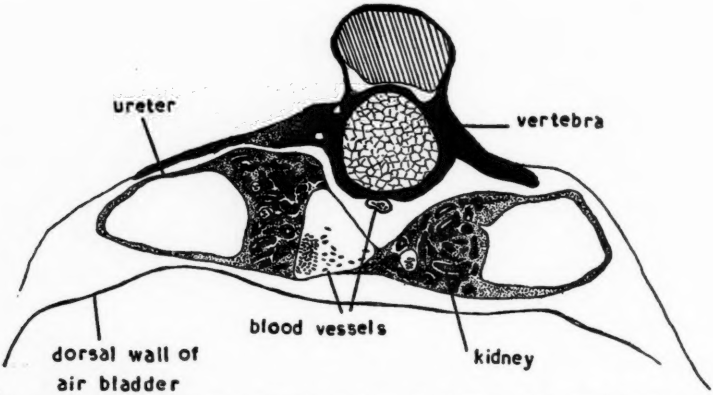

FIGURE 2.—Section through anterior portion of diseased kidney of largemouth bass fingerling showing the swollen ureters.

does not permit distribution by passenger train. Therefore, since a more effective means of transportation is at present not available, the fish have to be held over the summer months from December to April, and distributed from May to September. When reared in fertilized ponds over the summer, they grow so fast that by the time the cool weather sets in they are too large for distribution. By keeping them in circular rearing tanks and feeding them on a mixture of liver, fish, and salmon egg meal, it has been found possible to retard growth to the desired extent. Under these artificial conditions, however, the parasite of the ureters causes heavy losses among the largemouth bass, whereas smallmouth and spotted bass respond fairly well to this method of rearing.

Treatment.—At present the treatment of this disease is a case of prevention rather than cure. Since the entire life cycle of this trematode may be completed within the fish, and since, in any case, there is no intermediary host which can be eliminated, the control of the disease under artificial conditions is extremely difficult once it has made its appearance. The spread of the disease can be checked only by transferring the fish to fertilized earthen ponds as soon as the first signs of disease appear. This eliminates the crowded conditions, and on the natural food the fish quickly improve in condition. Sometimes even fish in advanced stages of infection overcome the disease and appear perfectly healthy except for the swollen condition of the region around the cloaca.

To prevent this disease, largemouth bass should be reared to the fingerling stage in fertilized earthen ponds, preferably of 0.1 acre or larger. Survival rates of 80 percent and more were obtained when

stocking such ponds at a rate of approximately 12,000 advanced fry per acre and draining the pond after about two months. These figures agree with results obtained by Meehean (1939) in Florida.

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FOOD HABITS OF THE SOUTHERN CHANNEL CATFISH (*ICTALURUS LACUSTRIS PUNCTATUS*) IN THE DES MOINES RIVER, IOWA[1]

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ABSTRACT

The stomach contents of 912 channel catfish (769 containing food) taken in a short section of the Des Moines River from September, 1940, to October, 1941, are analyzed. The physical and biotic characteristics of the study area are described; a partial list of the fishes present together with comments on their importance and relative abundance is included.

The channel catfish is omnivorous, as is revealed by a review of the pertinent literature and by this study. A wide variety of organisms is eaten (some 50 families of insects alone are represented—these are listed). Insects and fish serve as staple foods, plant seeds are taken in season, and various other items are eaten in limited numbers. The principal groups of foods (insects, fish, plants, and miscellaneous) are analyzed volumetrically, by frequency of occurrence, and numerically.

In the area studied, catfish grow at a rate of about 4 inches a year during the first 3 years of life (determined by length-frequency analysis). These natural size groups are utilized to establish the relationship between size and food habits. Young fish feed almost exclusively on aquatic insect larvae—chiefly midges, blackflies, mayflies, and caddis flies. In fish from 4 to 12 inches long insects continue to make up the bulk of the food, but at progressively greater size larger insects (mayflies and caddis flies) are eaten with increasing frequency and dipterans are of less importance than in the smaller size group; small fish and plant seeds become significant items of diet. In catfish more than 12 inches long, fish and large insects are of major importance, but many seeds and other items are taken. Although fewer insects are eaten by larger fish, those taken are more diversified and include a higher percentage of terrestrial forms.

Plant foods, chiefly of terrestrial origin, show the most striking seasonal trends of any of the food organisms. Seeds of the American elm in particular are taken in great numbers in May and June. Terrestrial insects are seasonal in appearance, being eaten at times of the principal flights. Aquatic dipterans are consumed consistently and in large numbers in the spring but progressively less frequently during the summer and fall; Trichoptera, however, are infrequently eaten in the spring but are of increased incidence in the summer and fall. These trends reflect changes in the numbers of organisms available. The numbers of the various species of forage fishes consumed are closely correlated with their relative abundance in the area. Several organisms which have been reported as important foods by other investigators (filamentous algae, microcrustaceans,

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crayfish, mollusks) are taken in insignificant quantity here, probably because these are rare in the Des Moines River.

In periods of low, relatively clear water, forage fish are eaten in sharply increased numbers—a reflection of their greater vulnerability. Feeding appears to be most active during the period from sundown until about midnight. Between 50° and 94° F., temperature does not seem to inhibit feeding, but in the winter the fish rarely feed. The available evidence indicates that adults do not feed during the breeding season.

In normal years reproduction of channel catfish is highly successful in prairie rivers. Efforts to increase production should be directed toward improvement of food supply and shelter facilities.

Introduction

The phenomena associated with or dependent on food and feeding relationships of fishes commonly dominate their ecological association. Growth rates are dependent to a large part on nutrition; the lack of an efficient population-limiting mechanism may result in such intense inter- or intraspecific competition for available food that growth cannot be maintained and stunting results. Food competition of undesirable species with game fish may effectively limit production of the more valuable forms. Similarly, predation on eggs, fry, or larger fish may reduce numbers or even eliminate species from a habitat. The mere mechanics of obtaining food by such bottom feeders as the carp and some suckers may, by increasing turbidity, profoundly alter the character of the environment to the detriment of valuable game species.

It becomes evident from these multiple and interrelated problems, still largely unanswered, that proper handling of the fishery resources calls for an understanding of the food-habit relationships of the chief game, non-game, and forage fishes.

The present investigation was designed as an intensive study of the food habits of the southern channel catfish, *Ictalurus lacustris punctatus* (Rafinesque), at a single locality. Thus, the results apply to one ecological situation and presumably are subject to more or less modification under other environmental conditions. The primary objectives of the investigation have been (1) to determine the qualitative and quantitative composition of the food eaten, including differences among young of the year, larger juveniles, and adults, (2) to determine daily and seasonal feeding trends, (3) to ascertain whether use of certain foods is favored, or if relative abundance, and size and habits of prey determine the quantities of various organisms consumed, and (4) to study the effects of such physical factors as temperature, fluctuation of water level, and turbidity on feeding behavior. Solution of all of these problems has not been fully achieved because of a necessary shortening of the contemplated period of field work and a sequence of heavy rains during the spring and early summer of 1941 when the specimens of certain sizes captured were too few for adequate determination of seasonal trends. The data presented are

based upon analysis of the stomach contents of 912 channel catfish taken during September and October 1940 and from April to October 1941 from the Des Moines River. Their sizes ranged from less than an inch to 23 inches, total length.

A preliminary summary of this paper has been published by us (Bailey and Harrison, 1943).

The southern channel catfish is distributed throughout most of the Mississippi basin and the rivers of the South Atlantic states and the Gulf coast from Georgia to northeastern Mexico. In the Great Lakes drainage and northward it is replaced by the scarcely differentiated subspecies, *Ictalurus lacustris lacustris* (Walbaum), and in western Texas and parts of Mexico by *Ictalurus lacustris lupus* (Girard). Primarily a bottom-living inhabitant of moderate to swiftly flowing streams, it may nevertheless be locally abundant in sluggish rivers and in lakes. In contrast to the bullheads (*Ameiurus*), most of which occur over mud-bottomed areas, the habitat preference of the channel catfish is for bottom composed of sand, gravel, rubble, or a mixture of these with mud—where *Ictalurus* is found over mud bottom, the water is usually flowing. Toleration to low dissolved-oxygen content and high concentrations of the products of organic decomposition is less well developed than in the bullheads. The channel catfish ranks as one of the most important commercial fish in the Mississippi basin, and is much sought by anglers, especially in the prairie and plains states where it is the chief game fish in many rivers of moderate to large size.

Description of Study Area

The Des Moines River, a former glacial outlet, is the longest stream in Iowa excepting the Mississippi and Missouri rivers. Arising in the moraines of Murray County, Minnesota, at an elevation of 1,850 feet, it flows in a southeasterly direction across Iowa to its confluence with the Mississippi just below Keokuk, 535 stream miles away, at 476 feet above mean sea level. Except for wooded stream valleys the upper portion of the drainage basin was originally prairie, generously sprinkled with marshes and shallow lakes. At present 64 percent of the drainage area is in cropland, 29 percent is in pasture, and few lakes or marshes remain. As a partial consequence, rains are attended by rapid runoff and fluctuations of water level in the streams are pronounced (Figs. 1 and 2). The river, which is normally murky, becomes very turbid after heavy precipitation and approaches clarity only during drought periods and in the winter.

The study area is located in Section 17, Worth Township, Boone County, Iowa, about midway along the river. It is approximately three-fourths of a mile in length, limited by the Sixteen-to-One Bridge on the north and the outlet of the Ledges State Park stream on the south. This locality lies in Wisconsin glacial drift, which extends south to Des Moines, about 35 miles downstream. The elevation is

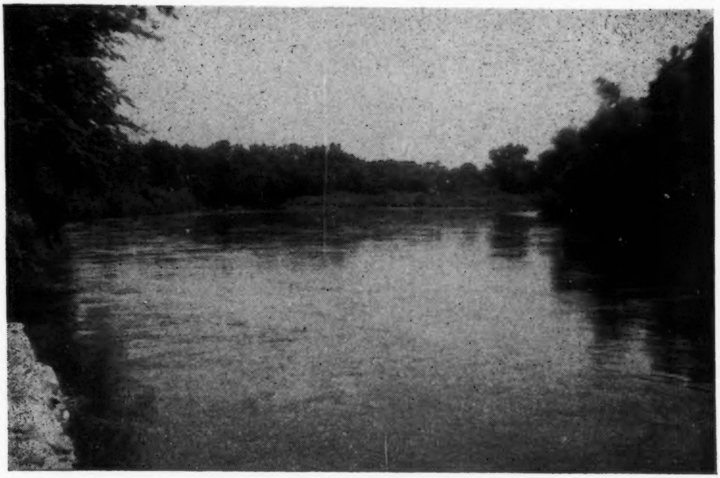

FIGURE 1.—A high-water stage of the Des Moines River. Down stream view of a portion of the study area.

FIGURE 2.—A low-water stage of the Des Moines River. Photograph taken from the same place as Figure 1, but at a slightly different angle. Note exposed rubble bottom (foreground) and drift jam (just left of center).

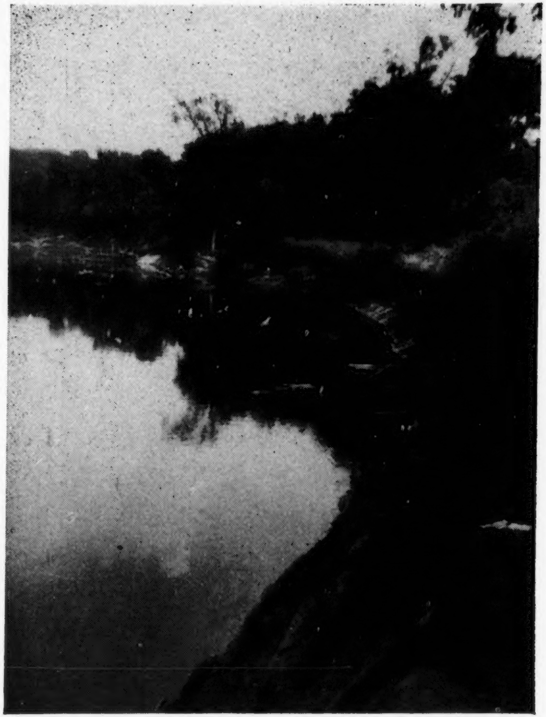

FIGURE 3.—Eroding bank on the outside of a meander of the Des Moines River. Floods may cut back several feet into such banks in a single year.

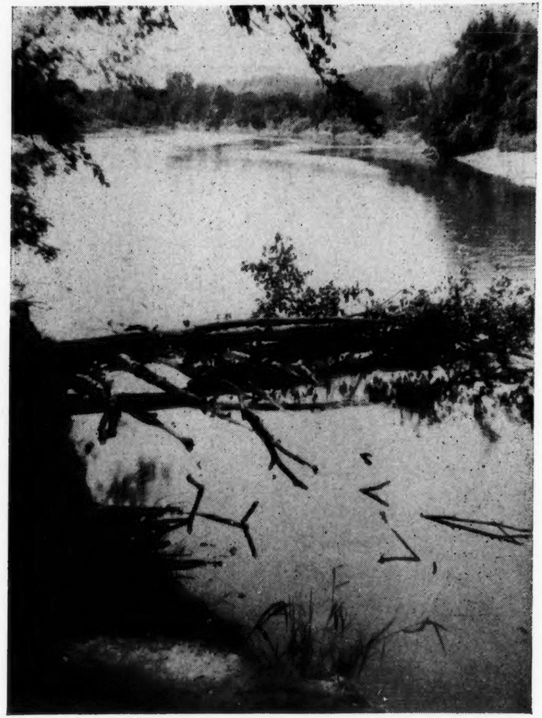

FIGURE 4.—Typical drift jam produced by a newly felled tree in which floating debris has been caught. Such sites harbor a rich insect fauna and provide excellent shelter for channel catfish.

855 feet and the stream gradient 2.53 feet per mile (computed from U. S. Geological Survey Topographic Maps). The adjacent bottomland and bluffs are for the most part heavily wooded, and, with the exceptions of sandbars, the shores are shaded by luxuriant undergrowth and willow, soft maple, American elm, box elder, ash, and basswood. On the outside of meanders the banks are nearly vertical, rising as much as 10 feet above the mean water level and falling steeply to a depth of 6 to 10 feet (Fig. 3). Water erosion along these banks periodically fells trees which accumulate floating brush and logs. The extensive masses of debris thus produced (Fig. 4) furnish ideal shelter conditions for fish and harbor a rich insect fauna. Wide, gradually sloping bars of sand and gravel are deposited on the inside of meanders. This section of the stream is a succession of long pools —about 8 feet deep—separated by rubble riffles and wide shallow bars of shifting sand. The channel is floored with coarse gravel and some boulders. Lateral bayous and lagoons are infrequent along the river and none is present in the area studied, but silt has been deposited in the backwaters and quite pools. The river averages about 200 feet in width during normal summer conditions, but fluctuations in depth and width are frequent and pronounced. The surface area of this portion of the stream is about 18 acres. Stream-flow records taken at the Boone Water Department (7 miles upstream and without important intervening tributaries) from 1921 to 1940 show the average discharge to be 1,240 second-feet—minimum 17 and maximum 24,300 (Crawford, 1942).

Biotic conditions are characterized by the rarity of aquatic vegetation and most invertebrates in contrast to the qualitative and quantitative richness of the fish fauna. Rooted aquatic vegetation is practically non-existent, but some algae occurs on rocks in riffle areas, and small quantities of a floating blue-green alga are evident in warm weather. The bottom fauna is very scanty. Only 461 organisms—total volume 11.45 cubic centimeters—were secured in 31 square-foot samples taken on all available bottom types from March to August with the Surber square-foot sampler. The square-foot sample average is 14.9 organisms with a mean volume of 0.37 cubic centimeter. With the exceptions of eight oligochaete worms, two gastropods and one isopod, all of the bottom organisms taken in the sampler were insects. Crayfish occur in small numbers. In contrast to the sparse bottom fauna, the down-timber, submerged brush, and log jams support a rich insect fauna and an abundance of the bryozoan, ***Plumatella fungosa.*** Although such situations occupy less than one percent of the stream area it would appear that they play a most important role in the production of fish food.

Fifty species of fishes have been collected in or adjacent to the study area in the Des Moines River (for a partial list and relative abundance of forage fishes see Table 4). More than half are small (predominantly minnows and darters) and of importance chiefly

as forage organisms. As indicated in Table 4, the spotfin shiner (*Notropis spilopterus*) is the most abundant fish in the stream, followed by the sand shiner (*Notropis deliciosus*). Together they constitute about 60 percent of the total number of small fish. Among game fishes, the channel catfish is at once the most abundant and the recipient of the bulk of the anglers' efforts. The walleye (*Stizostedion v. vitreum*) and the smallmouth bass (*Micropterus d. dolomieu*) are both rather common, and, judging from reports, their numbers are increasing. Four additional game or pan fishes (black bullhead, *Ameiurus m. melas;* flathead catfish, *Pilodictis olivaris;* black crappie, *Pomoxis nigro-maculatus;* and white crappie, *Pomoxis annularis*) are uncommon, and three (northern pike, *Esox lucius;* eel, *Anguilla bostoniensis;* and yellow perch, *Perca flavescens*) are very rare, apparently occurring only as transients or stragglers. Although no precise data are available, it seems fairly certain that the poundage of the larger non-game fish present is greatly in excess of that of the game species. Probably chief among these non-game species is the carp. Although fished for by many anglers, it was taken infrequently in our nets, presumably because of its recognized adeptness in eluding small seines. Ten species of suckers are present. None is taken by fishermen in significant quantity, but results of seining indicate that three species of carpsuckers (*Carpiodes*), three of redhorse (*Moxostoma*), bigmouth buffalofish (*Megastomatobus cyprinella*) and hogmolly (*Hypentelium nigricans*) are numerous. Their ecological relationship with the game species (as potential food, egg predators, and competitors for food) would seem to merit careful investigation.

Previous Food Studies of Channel Catfish

One of the most informative accounts of the food of the channel catfish was published by Forbes (1888). It was based on 43 specimens from the Illinois and Mississippi rivers. Insects were the principal food; they constituted 44 percent of the volume and occurred in 28 of the fish; 5 had eaten insects only, and 9 others had taken 90 percent or more of insects. Aquatic insects were the more common, but several of the fish had fed on terrestrial forms. Mollusks, about equally watersnails and thin-shelled clams (mostly *Anodonta*), were important elements, being found in 15 of the 43 specimens. They amounted to about 15 percent of the food, and several catfish had eaten little else. As many as 120 watersnails, *Melantho* [=*Campeloma*] and *Vivipara*, were taken from a single stomach. The absence of mollusk shells in the stomachs led Forbes to conclude that the shells are cracked in the jaws (snails) or separated from the soft parts (bivalves) and voided from the mouth before swallowing. Fragments of fishes occurred in 11 examples. Some catfish had evidently secured food from dead fish but others had taken them alive. The animal materials consumed included a dead rat and pieces of ham. About one-fourth of

the food consisted of vegetable matter, much of it miscellaneous and accidental. Three specimens had eaten nothing but algae; and fragments of pond-weed, *Potamogeton*, made up 20 percent of the diet of another three. The rarity of the floating *Lemma* was regarded as evidence of the strict bottom-feeding habits of the species.

McAtee and Weed (1915) studied the stomach contents of four adult channel catfish. The items found included the head and skin of an eel (*Anguilla*), seeds of the American elm, mayflies, a stonefly larva, a beetle, and vegetable debris.

Shira (1917) analyzed the stomach contents of 72 young channel catfish taken from rearing ponds at Fairport, Iowa. Midge larvae and mayfly nymphs were the most important items in the diet. The numbers of organisms eaten were roughly in proportion to their frequency in the ponds. At the same locality, Moore (1920) found insects (largely midges) and entomostracans to be the important items in the stomachs of 14 young catfish.

Three young specimens from New York examined by Sibley (1929) had eaten midges, other insect larvae, and *Gammarus*. Three adults had consumed fish, crayfish, insects, and plant fragments.

Ewers and Boesel (1935) investigated the stomach contents of five channel catfish (31 to 69 millimeters in total length) from Buckeye Lake, Ohio, and found the inclusions to consist of midges, copepods, and debris.

Aitken (1936) indicated that young quillback afford excellent forage for river catfish (presumably channel catfish).

Boesel (1938) studied the food of 61 channel catfish (34 to 101 millimeters in total length) taken at seven stations in Lake Erie between July 11 and August 29, 1929 and 1930. Insects (chiefly midge larvae and pupae and mayflies) made up 53 percent of the food by volume. Crustacea of many genera (principally cladocerans) constituted 33 percent of the diet. At some stations the food was composed predominantly of insects, at others of crustaceans. None of the larger catfish had fed to any extent on small crustaceans.

McCormick (1940) examined 14 specimens from Reelfoot Lake, Tennessee, and found caddis flies (38 percent by volume), filamentous algae (28 percent), and midge larvae (26 percent) to be the principal constituents of the food; fish made up 7 percent. In a continuation of this study at the same locality Rice (1941) analyzed 50 specimens and found 75 percent midge larvae and 25 percent caddis flies by volume.

On the basis of 38 specimens (3.1 to 10.6 inches long) from West Main Ditch, Imperial Valley, California, Dill (1944) found the catfish to be omnivorous. In analyses of frequency of occurrence and percentage volume midges, caddis fly larvae, Odonata, terrestrial insects and spiders, ooze (organic detritus and sand), and higher plants were of chief importance. Fish were infrequently taken but were exceeded in volume only by ooze. Five specimens from the Colorado River system

had consumed substantial quantities of aquatic plants (mainly *Najas*) and some backswimmers.

Channel catfish taken in the Chickahominy River, Virginia, during August (Menzel, 1945) had fed principally on filamentous green algae. February specimens were found to have eaten blue crabs (*Callinectes sapidus*) and a white perch (*Morone americana*).

Dendy (1946) analyzed the stomach contents of 75 catfish (230 to 409 millimeters in standard length) from Norris Reservoir. Gizzard shad [*Dorosoma cepedianum*], undetermined fish remains, and insects (both aquatic and terrestrial) were taken most frequently. Dendy found that fish became more important in the diet as the catfish increased in length. The gizzard shad appeared to be the principal food item.

Procedure

In order to permit analysis of daily and seasonal feeding trends, collections were taken at various times of day and throughout the seasons of availability. Field plans called for samples taken at intervals not to exceed 2 weeks, but during periods of high water, fish could be caught only with such difficulty that collecting was postponed.

Three methods were employed in obtaining fish and fish stomachs for this study. Twenty-two stomachs of legal-sized fish (12 inches and more, total length) were procured from anglers. Seining proved to be the easiest way to collect young and juvenile catfish, but the difficulty of handling nets effectively in deep, swift water and the failure to capture adult fish in significant numbers limited their use. Seining was accomplished with a 25- by 6-foot net of ⅓-inch-square mesh, provided with a 7-foot bag of ¼-inch mesh.

Most of the adult catfish were secured by gear commonly known to anglers as bank poles. Three-foot chalk lines equipped with 2/0 Kirby hooks were attached to slender green willow poles about 4 feet long. These rigs were set at night along steep banks of the stream by forcing the butts of the poles into the mud just above the water line. The baits bobbed about on or just beneath the surface of the water near shore. Minnows, either dead or alive, were found to be the best bait, but cheese, doughballs, mussel bodies, and fresh shrimp tails were also utilized. In order to prevent error in stomach analyses minnow baits were fin-clipped. This angling technique was effective in taking large fish, and was adapted to use in deep water or about submerged brush piles.

Catfish small enough to be preserved in 2-quart jars were fixed immediately in 4-percent formalin; for longer fish, the necessary data were taken and the stomachs were placed in small cloth sacks and preserved. After fixation, specimens were transferred to 70-percent alcohol for storage and subsequent examination.

Following removal from each stomach, the contents were separated into four groups: (1) insects; (2) fish; (3) plants; and (4) miscel-

laneous items—including bryozoans, mollusks, crustaceans, birds, mammals, and debris. The fourth category included items which appeared infrequently and usually in such small quantities that further division was believed unnecessary. The volume of each of these groups was estimated as a percentage. The contents were then washed in a fine sieve (40 meshes to the inch) to remove amorphous material. Examination of the wash water of early analyses revealed that no essential materials were lost. The residue from the sieve was placed in water in a Petri dish and examined under a binocular dissecting microscope. All food organisms found in each stomach were identified and counted. The presence of elytra, head capsules, and other relatively resistant parts permitted a reasonably accurate count of insects. The numbers of fish and seeds were easily determined since they were seldom digested to a condition such that counts were impossible. The enumeration of plants, other than seeds, and of some of the miscellaneous items presented difficulties. All fragments of plants, mollusks, crustaceans, birds, mammals, and colonies of Bryoza that occurred in a single stomach were arbitrarily assigned a numerical evaluation of one.

The data are segregated by seasons, and the fish are grouped into four size classes. The first group includes fish less than 4 inches in total (overall) length, the second those from 4 to 7.9 inches, the third those from 8 to 11.9 inches, and the last those 12 inches or greater. Recently-hatched catfish first appeared in our nets during early July. June specimens had all passed through one winter, but were less than 4 inches in total length. By July, however, these yearlings were all more than 4 inches in length and thus fell in the second size group. Subsequent annual growth, as determined by length frequencies, was relatively uniform for at least 2 years. Therefore the first three size-groups are composed largely of fish in their first, second, and third years of life, respectively. The fourth group includes fish of legal length (in Iowa).

Qualitative Composition of the Food

An imposing variety of animals and plants was found in stomachs of channel catfish from the Des Moines River, and, as indicated by the works of others, the species may indeed properly be termed omnivorous. Plant materials are consumed when available and aquatic insects and fish appear to serve as staple foods, but the catfish utilize various other animals and occasionally resort to scavenging. As might be expected from the diverse diet, many items are found infrequently and are regarded as fortuitous and therefore insignificant.

Insects dominate the food, especially of the smaller catfish. Aquatic larvae are more commonly used, but terrestrial insects are frequently eaten by larger catfish. In the tables and much of the succeeding discussion the insects are lumped by orders for the sake of brevity and simplification. However, during the analyses identifications were

carried as far as could be readily accomplished, and a list of the determinations is presented below. In order to indicate those species or categories of minor or incidental importance, an asterisk precedes each item which is represented in 10 or more of the 769 stomach containing food. The identifications in this list are our own.

List of Insects Contained in Catfish Stomachs

Orthoptera

Locustidae
- *Melanoplus differentialis*
- *M. femur-rubrum*

Tettigoniidae
- *Orchelimum vulgare*

Neuroptera

Corydalidae
- *Corydalus cornutus*

Myrmeleonidae
- *Myrmeleon* sp.

*Ephemeroptera

*Baetidae
- *Ameletus* sp.
- *Baetisca* sp.
- *Brachycercus* sp.
- *Caenis* sp.
- *Isonychia* sp.
- *Siphlonurus* sp.

*Ephemeridae
- *Ephoron* sp.
- *Hexagenia atrocaudata*
- *Hexagenia* sp.
- **Pentagenia* sp.
- **Potamanthus* sp.

*Heptageniidae
- **Heptagenia* sp.
- **Iron* sp.
- *Stenonema* sp.

Odonata

Gomphidae
- *Gomphus* sp.

Cordulegasteridae
- *Cordulegaster maculatus*

*Plecoptera

Perlidae
- *Acroneuria lycorias*
- *Neophasganophora capitata*
- *Perla hastata*
- *Perlesta* sp.

*Hemiptera

*Corixidae
- **Arctocorisa* sp.

Miridae
- *Lygus pratensis*

Pentatomidae
- *Podisus maculiventris*

Reduviidae

*Homoptera

Aphididae

Cicadellidae

Membracidae
- *Atymna querei*
- *Ceresa diceros*

Cicadidae
- *Tibicen auletes*

*Coleoptera

Buprestidae

Carabidae
- *Evarthrus colossus*

Chrysomelidae
- *Diabrotica duodecim-punctata*
- *Lina interrupta*

Coccinellidae
- *Hippodamia* sp.
- *Megilla maculata*

Erotylidae

Gyrinidae
- *Gyrinus* sp.

Haliplidae
- *Peltodytes* sp.

Hydrophilidae
- *Berosus striatus*
- *Hydrous triangularis*
- *Enochrous* sp.

*Dytiscidae
*_Dytiscus_ sp.
Curculionidae
*Elmidae
*_Elmis_ sp.
Lathridiidae
Scarabaeidae
Geotrupes sp.
Phyllophaga sp.
Silphidae

*Trichoptera

*Leptoceridae
*_Setodes_ sp.
*Hydropsychidae
*_Hydropsyche_ sp.
Phryganeidae
Sericostomatidae
Brachycentridae
Brachycentrus sp.
Helicopsychidae
Helicopsyche borealis

Lepidoptera

*Diptera

*Tendipedidae (=Chironomidae)
Dolichopodidae
Muscidae
Psychodidae
Psychoda sp.
Sarcophagidae
Sarcophaga sp.
*Simuliidae
*_Simulium_ sp.
Stratiomyidae
Euparyphus sp.
Stratiomyia sp.
Tabanidae
Tabanus sp.
*Tipulidae
*_Antocha_ sp.
Pedicia sp.
Ptychoptera sp.
Rhamphidia sp.
Rhaphidolabis sp.

Hymenoptera

Formicidae
Vespidae

Only four orders of insects contribute heavily to the food (see Table 2). Among the Diptera the tendipedids (chironomids) are of greatest importance, and indeed comprise the great bulk of the food of young catfish, but blackfly larvae (_Simulium_) are also commonly found. Mayflies (Ephemeroptera) are second in importance, chiefly because of the large number of nymphs of _Potamanthus_ and _Pentagenia._ Caddis flies (Trichoptera) are of value largely through the abundant appearance of larval hydropsychids. The beetles (Coleoptera) most often taken are aquatic forms (_Elmis_ and _Dytiscus_), but terrestrial species appear frequently.

The fishes, plants, and other organisms eaten are listed in Table 2. The relative importance of the various forms as determined on the basis of frequency of occurrence is indicated.

Minnows (Cyprinidae) are dominant among the fish foods, no less than 14 species being encountered. A sucker, a darter, and small channel catfish also were recorded.

Plant foods are not usually a major item except during the fruiting season of the American elm (_Ulmus americana_). At this time the seeds are eaten freely by all but the smallest catfish. The Des Moines River in this area is practically devoid of aquatic vegetation, a circumstance which explains the infrequent use of vegetable materials in contrast to the relatively greater importance of such foods as deter-

mined by Forbes (1888). Most of the records of plant materials are based on seeds, but an occasional leaf is found, and debris (often ingested incidentally from the cases of the caddis fly, *Setodes* sp.) is frequently noted.

Crustaceans, pelecypods, and gastropods—found to be significant foods in studies by Forbes (1888), Moore (1920), Ewers and Boesel (1935), and Boesel (1938)—are little used by catfish in the Des Moines River. The obvious explanation for this difference hinges on the rarity of these organisms in the area.

The bryozoan *Plumatella fungosa* is consumed commonly.

The stomach of one adult catfish was filled with coal, and another had ingested several small pieces. Sand, presumably taken accidentally, was encountered on several occasions.

Fish bait, such as doughball, liver, and shrimp tails taken either from the hook or from discarded bait cans, made up a considerable part of the stomach content of several fish.

Quantitative Composition of the Food

Students of food habits of animals differ in their methods of quantitative analysis. Some favor volumetric or weight measurement; others prefer to record presence or absence of a given item and use frequency of occurrence as a quantitative index. Still others endeavor to count the number of individual organisms in each sample. Proponents of the frequency-of-occurrence method contend that this is the easiest analysis to make, and hold that volumetric and item-count determinations are subject to gross inaccuracy because of differential digestion and the fragmentation of organisms, especially through mastication. These arguments appear often to be valid, as in analyses of feces or intestinal contents, and for those animals which chew the food thoroughly. For stomach analyses of most fish, however, the volumetric method seems usually to provide a more valuable index. By this method, for example, analysis of a stomach containing an adult crayfish and two midge larvae would emphasize the greater importance of the former. By the presence-or-absence criterion, both food organisms would be recorded simply as present, and by item count the midge would be given twice the value of the much larger crayfish. Multiplication of the mean size of an organism and its frequency in a stomach gives, in effect, a volumetric measurement. Digestion in the catfish stomachs was rarely so far advanced as to affect seriously volumetric analysis, but intestinal contents were rejected because of dissolution.

In this study the four principal categories of foods (page 118) are analyzed volumetrically, by frequency of occurrence, and numerically. The results, arranged by size-groups of the catfish, are summarized in Table 1. Comparison of the volumetric and frequency-of-occurrence analyses is given in Figure 5. Except for the small catfish, which feed almost entirely on insects, it is seen that the frequency of occur-

TABLE 1.——*Major foods of four size groups of the channel catfish from the Des Moines River.*
[Expressed as averages of the estimated percentage volumes, percentage frequencies of occurrence, and average numbers of items contained in the stomachs.]

Food group	Total length and number of stomachs containing food											
	Less than 4 inches			4.0-7.9 inches			8.0-11.9 inches			12 inches or more		
	410			221			59			79		
	Percentage volume	Percentage frequency of occurrence	Average number items	Percentage volume	Percentage frequency of occurrence	Average number items	Percentage volume	Percentage frequency of occurrence	Average number items	Percentage volume	Percentage frequency of occurrence	Average number items
Insects	98	99	6.0	77	97	11.1	58	90	11.3	28	80	7.2
Fish	1	4	....[2]	8	22	0.3	12	22	0.4	35	47	1.9
Plants	1	2	....[2]	11	34	5.3	23	46	29.5	19	46	23.3
Others	....[1]	2	....[2]	4	6	0.1	7	10	0.2	19	18	0.2

[1]Less than 0.5 percent.
[2]Less than 0.05 item.

rence magnifies the relative importance of small organisms (insects and plant seeds) in any size-group. Thus, in those catfish 12 inches

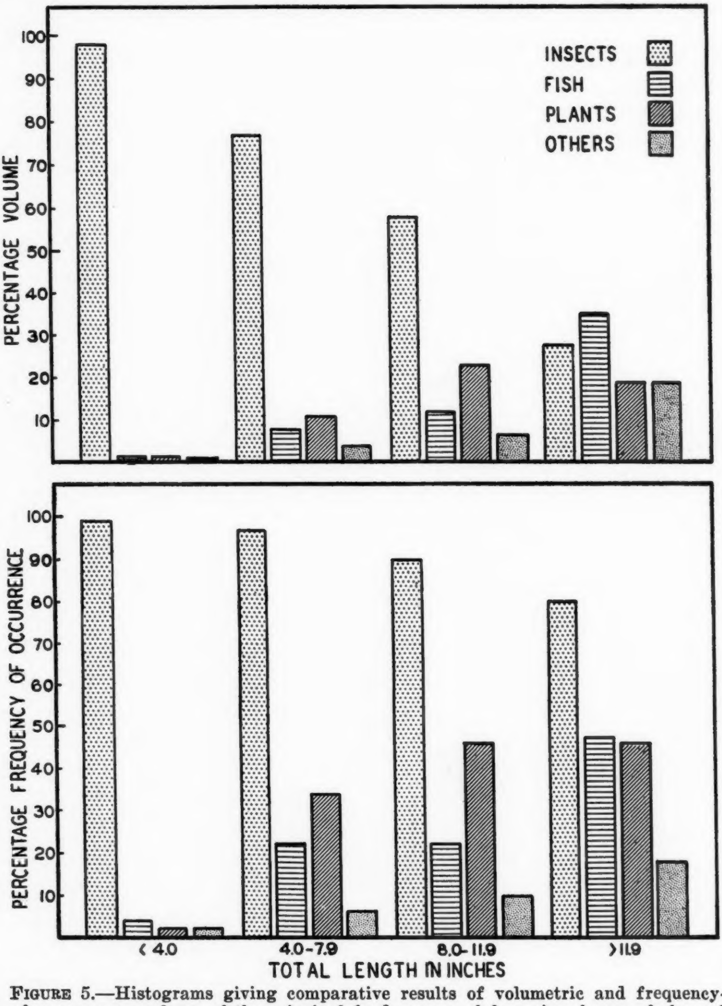

FIGURE 5.—Histograms giving comparative results of volumetric and frequency-of-occurrence analyses of the principal food groups of four size classes of channel catfish from the Des Moines River (data from Table 1).

or more in length, fish are less important than insects as determined by frequency of occurrence, but are more important as measured volumetrically. Miscellaneous foods are encountered less than half as often as plant materials, but bulk the same. The item count of organisms appears to be especially instructive in the discernment of seasonal trends and the relationship of size to food habits.

Although determination of volumes appeals to us as the best single method of stomach analysis, it was not used in this study in the breakdown to specific food organisms (Table 2). The wide variety of foods and their small volumes posed problems which are handled most effectively by use of frequency-of-occurrence and item-count methods.

Size in Relation to Foods Consumed

The food habits of small and large channel catfish are markedly different. Small insects constitute the bulk of the food of young fish, whereas the diet of adult fish is diversified and is dominated by organisms of larger size. Ninety-nine percent of catfish under 4 inches long had eaten insects amounting to 98 percent of the volume of food. In contrast, insects had been consumed by 80 percent of fish 12 inches or longer, but bulked only 28 percent of the food. The major groups of foods are compared in Table 1 and the percentage volumes and frequencies of occurrence of the various categories are presented as histograms in Figure 5. Counts of the number of individual organisms in the stomachs show an increase of from 6 insects in fish less than 4 inches in length to an average of more than 11 in fish from 4 to 12 inches, but larger specimens contain only about 7 insects. Forage fish, negligible in the smallest group, average about one to every two or three stomachs of half-grown fish, but legal catfish eat an average of almost 2 forage fish each. Young catfish rarely consume plant materials, but specimens 8 inches or longer average over 20 seeds (the precise average figures are not of great significance because of the marked seasonal appearance of American elm fruits and the occasional discovery of enormous numbers of these seeds in a stomach). Other foods never provide high item counts but appear most frequently and in greatest bulk in large fish.

It is indicated above that there is an inverse relationship between size of catfish and the importance of insects in the diet. There is also a positive correlation between size of fish and size of insect prey (Table 2). The dipterous larvae in the Des Moines River consist principally of small forms, chiefly tendipedids and simuliids. These, the most abundant small though macroscopic organisms in the river, make up 81 percent of the aquatic insects in the stomachs of catfish under 4 inches in length (Table 4). In successively larger size groups of fish, Diptera make up 65, 71, and 12 percent of the aquatic insects consumed. Frequency-of-occurrence analysis shows that 80, 77, 41, and 29 percent respectively of the fish in the four size groups had eaten Diptera. In the larger size groups dipterans sometimes equal the

TABLE 2.—*Percentage frequencies of occurrence of foods of different size groups of channel catfish, arranged to show seasonal trends.*

[Percentages are based on the number of stomachs containing food; totals are weighted averages, not averages of seasonal percentage frequencies]

Food	Size group[1] and number of stomachs containing food during:															
	April-June				July-August				September-October				All months			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	16	83	16	5	133	47	26	39	261	91	17	35	410	221	59	79
Insects	100	98	100	100	98	98	88	90	99	97	82	66	99	97	90	80
Aquatic	100	98	94	80	94	96	69	85	97	85	71	66	96	92	76	76
Terrestrial	....	....	56	100	1	13	12	28	5	18	12	9	3	19	24	24
Undetermined	13	10	6	20	14	13	19	3	22	21	12	6	19	15	14	5
Determined	100	98	100	100	94	96	69	87	92	87	71	66	93	93	78	78
Orthoptera	....	....	....	....	1	....	....	5	....	1	12	....	....[2]	....[2]	3	3
Neuroptera	....	2	....	....	....	2	12	....	....	....	....	3	....	1	5	1
Ephemeroptera	63	73	75	60	30	74	42	44	36	41	24	14	35	60	46	32
Odonata	....	4	....	....	....	2	....	5	1	1	....	3	....[2]	2	....	4
Plecoptera	....	5	....	....	....	....	8	3	....[2]	....	....	3	....[2]	2	3	3
Hemiptera	....	16	....	40	1	4	....	15	2	13	....	3	1	12	....	11
Homoptera	....	6	....	....	....	....	4	5	2	5	....	....	1	5	2	3
Coleoptera	6	37	56	100	2	15	8	15	7	16	18	20	6	24	24	23
Trichoptera	25	35	19	40	19	81	58	74	38	49	41	29	31	51	42	52
Lepidoptera	6	2	....	....	....	....	....	....	....	1	....	3	....[2]	1	....	1
Diptera	94	81	63	20	86	79	31	38	77	73	35	20	80	77	41	29
Hymenoptera	....	4	....	....	....	4	8	5	3	2	....	....	2	3	3	3
Fish scales	....	14	....	40	....	13	12	10	5	10	24	11	3	12	12	13
Fish eggs	....	6	....	....	....	....	....	....	....	....	....	....	....	2	....	....
Fish	....	4	6	40	1	11	15	31	1	8	24	46	1	7	15	38
Undetermined	....	....	....	....	1	....	4	3	1	....	....	9	1	....	2	5
Determined	....	4	6	40	....	11	12	31	....	8	24	43	....	7	14	37
Catostomidae (undetermined)	....	....	....	....	....	....	....	3	....	....	....	....	....	....	....	1
Carpiodes spp.	....	....	....	....	....	....	....	3	....	....	....	....	....	....	....	1
Cyprinidae (undetermined)	....	....	....	20	....	....	4	10	....	....	....	....	....	....	2	6
Erimystax sp.	....	....	....	....	....	....	....	....	....	....	....	3	....	....	....	1
Extrarius aestivalis	....	1	....	....	....	....	....	....	....	....	....	....	....	....[2]	....	....
Notropis (undetermined)	....	1	....	....	....	....	....	10	....	1	6	....	....	1	2	5
Notropis a. atherinoides	....	....	....	....	....	....	....	....	....	....	6	9	....	....	2	4
Notropis rubellus	....	....	....	....	....	2	....	....	....	1	....	6	....	1	....	3
Notropis cornutus frontalis	....	....	....	....	....	....	....	....	....	....	12	14	....	....	3	6
Notropis d. dorsalis	....	....	....	....	....	....	....	5	....	....	....	14	....	....	....	9
Notropis spilopterus	....	1	....	20	....	9	4	8	....	5	18	37	....	5	7	22
Notropis d. deliciosus	....	....	....	....	....	....	4	5	....	....	12	29	....	....	5	15

TABLE 2—*continued*

[Percentages are based on the number of stomachs containing food; totals are weighted averages, not averages of seasonal percentage frequencies]

	Size group[1] and number of stomachs containing food during:															
	April-June				July-August				September-October				All months			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Food	16	83	16	5	133	47	26	39	261	91	17	35	410	221	59	79
Notropis topeka	....	....	....	....	....	....	....	....	....	....	....	3	....	....	....	1
Phenacobius mirabilis	....	....	....	....	....	....	....	....	....	....	....	6	....	....	....	3
Ceratichthys perspicuus	....	....	....	....	....	....	....	....	....	1	6	17	....	....[2]	2	8
Hyborhynchus notatus	....	....	6	....	....	....	....	....	....	....	....	11	....	....	2	5
Pimephales p. promelas	....	....	....	....	....	....	....	3	....	....	....	11	....	....	....	6
Ictalurus lacustris punctatus	....	....	....	....	....	....	....	3	....	....	....	....	....	....	....	1
Boleosoma n. nigrum	....	....	....	....	....	....	....	....	....	....	....	6	....	....	....	3
Plant	....	58	69	60	....	19	42	59	3	20	29	29	2	34	46	46
Debris	....	11	13	....	....	11	27	41	....	10	6	20	....	10	17	29
Undetermined	....	2	....	....	....	6	12	15	2	5	6	3	1	5	7	9
Determined	....	52	56	60	....	2	4	18	....[2]	5	18	23	....[2]	22	22	23
Vaucheria sp.	....	1	6	....	....	....	....	....	....	....	....	....	....	....[2]	2	....
Poa pratensis	....	....	....	....	....	....	....	3	....	....	6	....	....	....	2	1
Zea mays	....	....	....	....	....	....	....	8	....	....	....	14	....	....	....	10
Salix sp.	....	....	....	....	....	....	....	....	....	....	....	3	....	....	....	1
Quercus sp.	....	....	....	....	....	....	....	3	....	....	....	....	....	....	....	1
Ulmus americana	....	51	56	60	....	....	....	....	....	....	....	....	....	19	15	4
Celtis occidentalis	....	....	....	....	....	....	4	....	....	....	....	....	....	....	2	....
Polygonum perspicaria	....	1	6	....	....	2	....	....	....	2	6	....	....	2	3	....
Amaranthus sp.	....	1	....	....	....	....	....	....	....[2]	1	....	....	....[2]	1	....	....
Acer negundo	....	1	....	....	....	....	....	....	....	....	....	....	....	....[2]	....	....
Vitis sp.	....	....	....	....	....	....	....	....	....	2	12	3	....	1	3	1
Cornus sp.	....	....	....	....	....	....	....	3	....	....	....	....	....	....	....	1
Ambrosia artemisiifolia	....	....	....	....	....	....	....	3	....	....	....	....	....	....	....	1
Ambrosia trifida	....	....	....	....	....	....	....	....	....	....	....	3	....	....	....	1
Bryozoa (*Plumatella fungosa*)	....	1	....	....	2	6	4	....	....	3	....	....	....[2]	3	2	....
Gastropods	....	....	....	....	....	2	....	....	....	3	6	....	....	2	2	....
Amnicola sp.	....	....	....	....	....	....	....	....	....	2	....	....	....	1	....	....
Planorbis sp.	....	....	....	....	....	2	....	....	....	1	....	....	....	1	....	....
Cambarinae	....	1	....	....	....	....	4	8	....	....	18	9	....	....[2]	8	8
Hydrachnidae	....	1	....	....	....	....	....	....	1	....	....	....	1	....[2]	....	....
Birds	....	....	....	....	....	....	....	5	....	....	....	3	....	....	....	4
Gallus gallus	....	....	....	....	....	....	....	5	....	....	....	....	....	....	....	3
Passerine (undetermined)	....	....	....	....	....	....	....	....	....	....	....	3	....	....	....	1
Mammal (hair)	....	1	....	....	....	....	....	13	....	....	....	....	....	....[2]	....	6

[1]Size-group 1 includes catfish less than 4 inches in total length, group 2 those from 4.0 to 7.9 inches, group 3 individuals from 8.0 to 11.9 inches, and group 4 fish 12.0 inches or longer.

[2]Less than 0.5 percent.

number or frequency of ephemeropterans and trichopterans, but are regarded as less important because of their smaller bulk. The Ephemeroptera are somewhat larger; the forms most commonly consumed are nymphs of *Potamanthus, Pentagenia,* and *Heptagenia.* It appears that they are utilized most by the yearling and 2-year-old fish. Of all the aquatic insects eaten, mayflies constitute 9, 15, 18, and 13 percent in increasingly larger size groups, and 35, 60, 46, and 32 percent of the fish in the several groups feed on them. Trichoptera are small insects, but because of their protective cases only the larger catfish prey on them effectively. *Hydropsyche* sp. is easily the dominant caddis fly; *Setodes* sp. appears only about one-tenth as often and other forms even less frequently. Trichopterans make up only 8 percent of the aquatic insects eaten by young catfish, but comprise 72 percent of those taken by fish 12 inches or longer (Table 3). That all size groups eat caddis flies, at least in small numbers, is indicated by the percentages of occurrence: 31, 51, 42, and 52 (Table 2). Other insects are eaten in small numbers; no more than 2 percent of the aquatic insects eaten by any size group belong to an order other than the Diptera, Ephemeroptera, and Trichoptera. Nevertheless, nearly one-fourth of the catfish in each of the three larger size groups consume Coleoptera (chiefly *Elmis* sp. and *Dytiscus* sp.), and they often take Hemiptera (especially *Arctocorisa* sp.)—see Table 2. Insects provide a smaller proportion of the diet in large than in young catfish, but a wider variety is consumed: most of the numerous kinds taken infrequently (see pp. 120-121) are encountered only in the half-grown to adult fish.

Aquatic insects predominate over terrestrial species in all size groups, but the latter are taken more frequently by the larger fish (Table 2). Aquatic species are found in 96 percent of the stomachs of catfish less than 4 inches long, terrestrial insects in only 3 percent. Among legal fish 76 percent contain aquatic insects, 24 percent terrestrial kinds. The explanation for the increased use of terrestrial insects by larger fish involves the mechanical advantage of greater size, more favorable choice of habitat, and probably less restriction to bottom feeding. Many terrestrial insects are available to large catfish, but are too large for the young fish to engulf. Larger catfish most often inhabit deep water, which is usually near the eroding banks on the outside of meanders. Here much vegetation overhangs the stream and terrestrial insects frequently drop to the water, where they are available to the large catfish. In contrast, the shoal areas preferred by young catfish lie in the middle of the stream or near shelving sand bars on the inside of meanders, and few terrestrial insects drop to the water, although some float by. We know little of the feeding behavior of young catfish from direct observation, but suspect that they do most of it on the bottom. The nature of the food eaten confirms this belief. The adult fish, though characteristically bottom feeders, frequently rise to the surface to eat (see description of one method used to take

adult catfish for this study, p. 118). This apparently greater latitude in feeding behavior explains in part the higher incidence of terrestrial insects in the diet.

Fish scales not associated with other remains are encountered rarely in young catfish, frequently in the larger size-groups. It is possible that some of these scales represent specimens which have otherwise passed into the intestine, but we believe that they are ingested chiefly when scavenging or, more commonly, as single isolated scales. Because of their insignificant volume and questionable nutritive value they are segregated from the fish eaten (Table 2). Fish eggs occur in five catfish between 4 and 8 inches in length taken during May, but no stomach contains more than three eggs. It is apparent that at this locality channel catfish are of minor importance as egg predators.

Fish are negligible in the food of young catfish and of limited importance to yearlings and 2-year-olds, but on a volumetric basis constitute the principal food group in the adults. Three young catfish (2.0, 2.2, and 2.3 inches in length) of the 410 with food contain fry which are too badly mutilated to permit identification. Minnows occur in 7 percent of catfish 4.0 to 7.9 inches long and in 14 percent of those from 8.0 to 11.9 inches. Thirty-seven percent of the adults contain fish (Table 2). Forage fish are constantly present in abundance, but because of their size and agility are not vulnerable to predation by small catfish. These safeguards are less effective against the larger, faster, and stronger adults.

Plant materials are virtually absent from the stomachs of catfish less than 4 inches in length, but the larger fish use them commonly when available. Plants, among all catfish foods, are most sharply seasonal in appearance. This situation is readily understandable since (except for debris, an occasional leaf, or a strand of *Vaucheria*) the materials consist of seeds from terrestrial plants. Because of differences in the seasonal distribution of samples among the several size groups of catfish, the overall averages are subject to error. Vegetable debris becomes increasingly frequent in the larger fish. It usually occurs in small volume, and is probably taken incidentally or in cases of the trichopteran, *Setodes* sp. (*Setodes* also appears with increasing frequency in successively larger fish.) Fruits of the American elm dominate the plant foods (Table 2). They are not eaten by catfish less than 4 inches long, but occur with approximately equal frequency in spring samples of the three other size groups. It is of interest that these fruits usually appear without their seed coats. Presumably the seed covers are removed in a manner comparable to that described by Forbes (1888) for the separation of mollusk shells from the soft parts. Occasionally over 100 elm seeds occur in a single stomach. One catfish 12.5 inches long contains 1,129 of these seeds, and three smaller specimens have 647, 576, and 262. Corn (*Zea mays*), found only in the stomachs of seven legal fish, is usually represented by not more than one or two kernels.

Miscellaneous animal foods are taken rarely by catfish less than 4 inches in length, not infrequently by fish from 4 to 12 inches long, and rather commonly and in appreciable quantity by legal-sized fish (Table 2). Most of these organisms are too large to be consumed by small catfish. It is probable that if crayfish and snails were common in the area they would contribute heavily to the food of the large fish.

Seasonal Food Trends and Availability of Food Organisms

Seasonal changes in the food of the channel catfish are gradual and, usually, slight. For the most part they are characterized by a shift in the relative importance of certain items or groups of organisms rather than by a sharp break from or to a different diet. Plant foods, which are almost entirely of terrestrial origin, present the most marked seasonal fluctuations (Table 2). Seeds of the American elm are eaten abundantly during May and sometimes in June, but never at other times. Seeds of the wild grape (*Vitis* sp.) appear only in the fall, corn in late summer and fall. Terrestrial insects, too, are seasonal in appearance. During May, the month of the principal beetle flights, these insects are more common than at other times, but most species of other aerial insects are eaten only or chiefly during the late summer and fall.

We have attempted to determine the seasonal relationship between the numbers of aquatic insects present in the Des Moines River and their relative frequency in the stomachs of channel catfish. Toward this end, samples were taken from representative bottom types each month from April through September. The total numbers of insects secured, together with the percentage composition of each order represented, are recorded by seasons in Table 3.[3] Diptera, which constitute 68 percent of the total in the spring, decrease in relative numbers as the season progresses so that by September they make up only 16 percent. Simultaneously the Trichoptera increase from 10 to 81 percent, and the Ephemeroptera decrease from 11 to 2 percent. Other groups are of relatively minor importance. In line with these marked changes in the bottom fauna, it is noted that the number of insects in catfish stomachs varied too (Table 3). Diptera, although not eaten in large numbers by legal fish, are of major importance in the spring in fish under 12 inches in length. In the summer and fall, however, fish of all sizes eat relatively smaller numbers of them. Trichoptera are of little importance as a spring food, but become very numerous in the stomachs during the summer and fall, far outnumbering the Diptera in fish over 8 inches long. Despite the decrease in numbers of Ephemeroptera noted in the bottom samples as the season progresses, there is no reduction in their frequency in the stomach contents, and they are eaten most often in the summer. Examination

[3]It is a matter for regret that we failed early enough to recognize the important role which floating log jams and large masses of branches and debris play in the production and harboring of aquatic insects. The contribution of such areas may materially alter the relative figures determined from bottom sampling alone.

TABLE 3.—*Comparison of the numbers of aquatic insects eaten by channel catfish with the numbers in the Des Moines River (determined by bottom sampling in 1941).*

[Numbers are expressed as percentages to facilitate comparison]

Order	Size group of fish[1] and number of insects taken in the river and in stomachs during:																			
	April-June					July-August					September					All months				
	River	Stomachs				River	Stomachs				River	Stomachs				River	Stomachs			
		1	2	3	4		1	2	3	4		1	2	3	4		1	2	3	4
	237	174	1,168	394	19	245	851	410	79	260	323	278	180	18	115	805	1,303	1,758	491	394
Neuroptera	....	....	....	....	....	1	....	....[2]	4	....	....[2]	....	....	....	....	....[2]	....	....[2]	1	....
Ephemeroptera..	11	7	12	14	68	5	8	25	38	12	2	13	13	11	6	5	9	15	18	13
Odonata	2	....	....[2]	....	....	1	....	....[2]	....	1	....	....[2]	....	....	2	1	....[2]	....[2]	....	1
Plecoptera	....[2]	....	....[2]	....	....	....[2]	....	....	4	....[2]	....[2]	....	....	....	....	....[2]	....	....[2]	1	1
Hemiptera	6	....	1	....	5	1	....[2]	1	....	....[2]	....	....	....	....	....	2	....[2]	1	....	1
Coleoptera	2	1	2	....	5	3	3	1	3	....[2]	....	2	2	11	....	1	2	2	1	1
Trichoptera	10	3	4	1	....	36	6	48	42	73	81	15	24	44	82	46	8	16	9	72
Diptera	68	88	80	85	21	53	83	25	10	13	16	69	61	33	10	43	81	65	71	12

[1]Size group 1 includes catfish less than 4 inches in total length; group 2, those from 4.0 to 7.9 inches; group 3, individuals from 8.0 to 11.9 inches; and group 4, fish 12.0 inches or longer.

[2]Less than 0.5 percent.

of the floating masses of debris reveals large numbers of mayflies, and this source, which is available to the fish, probably explains the apparent lack of correlation in numbers available and insects eaten.

It is recognized that the relative numbers of various organisms present in a habitat do not constitute a true ratio of availability (Hess and Swartz, 1941; Allen, 1942; Leonard, 1942). Some (trichopterans) have cases which need to be broken to release the larva—a difficult task for a small fish; others seek seclusion in the bottom or beneath objects, and thereby realize a measure of protection; still others gain advantages because of size, speed, or protective adaptations. Nevertheless, and within the limits of our admittedly inadequate data, it seems to be true that the predation of channel catfish on aquatic insects is roughly correlated with their relative abundance.

In order to ascertain the relative numbers of various species of potential forage fishes occurring in the study area, the catch of several seine hauls was counted each month from May to September. The largest fish included in the enumeration are approximately 3 inches in total length, since larger specimens are not eaten by the catfish. The area sampled extends from a sand and gravel meander bar to a depth of about 5 feet, and is easily seined. (The majority of the catfish which where seined for the study were caught in the same area, and those taken on hook and line were captured along the opposite bank in deeper water.) Although the samples vary somewhat among themselves they are surprisingly consistent in that they exhibit no apparent seasonal trend, and the overall percentage composition, based on 1,485 specimens, is regarded as reliable for the specific area.

Of the 157 fish taken from stomachs 16 are from catfish 4 to 7.9 inches in total length, 17 from those 8 to 11.9 inches, and 124 are found in legal-sized catfish. The great majority (124) are in September samples, partly because more large catfish were secured in September than during any other month, but also because forage fish were more vulnerable than earlier in the year (see p. 134).

The spotfin shiner (*Notropis spilopterus*) is the dominant small fish in the river (49 percent) and provides 43 percent of the fish eaten by channel catfish (Table 4). The sand shiner (*Notropis d. deliciosus*) ranks second in abundance (18 percent) as well as in catfish food (17 percent). The bullhead minnow (*Ceratichthys perspicuus*) composes 5 percent of the fish seined and 10 percent of the fish food of catfish. These three species together include 72 percent of the forage fish and 70 percent of the fish eaten. A comparison of the corresponding figures for the species listed in Table 4 reveals a remarkably close correlation throughout, and it is evident that no marked preference or selection of specific fish foods is practiced by the catfish. The slightly greater use of some species than their appearance in seined samples would suggest, might be interpreted as indicating a close habitat association with, and increased vulnerability of these

TABLE 4.—*Comparison of the numbers of fish eaten by channel catfish with the numbers present in the study area of the Des Moines River (determined by random seining).*

[Tabulated counts include only fish smaller than the largest found in catfish stomachs]

Item	Number of fish in river and in catfish stomachs							
	May-June		July-August		September		All months	
	River	Stomachs	River	Stomachs	River	Stomachs	River	Stomachs
	516	4	512	29	457	124	1,485	157
Carpiodes sp.[1]	3	....	2	3	....	....	2	1
Erimystax sp.	....	....	....[3]	....	....	1	....[3]	1
Extrarius aestivalis	....	25	....[3]	....	....[3]	....	....[3]	1
Notropis a. atherinoides	2	....	3	....	4	4	3	3
Notropis rubellus	1	....	2	3	1	2	1	2
Notropis cornutus frontalis	1	....	1	....	1	8	1	7
Notropis d. dorsalis	1	....	....[3]	7	2	4	1	4
Notropis spilopterus	50	50	51	62	46	38	49	43
Notropis d. deliciosus	16	....	17	10	23	19	18	17
Notropis topeka	....	....	1	....	....[3]	1	....[3]	1
Phenacobius mirabilis	1	....	2	....	2	2	2	1
Ceratichthys perspicuus	7	....	4	....	4	13	5	10
Hyborhynchus notatus	8	25	6	....	5	4	6	4
Pimephales p. promelas	3	....	3	3	3	3	3	3
Ictalurus lacustris punctatus	1	....	1	10	4	....	2	2
Boleosoma n. nigrum	2	....	1	....	2	2	2	1
Other species[2]	6	....	6	....	3	....	5	....

[1]Young specimens of *Carpiodes* are identified with difficulty; *C. c. carpio*, *C. cyprinus*, and *C. velifer* occur in the study area.

[2]*Moxostoma anisurum*, *M. erythrurum*, *M. aureolum*, *Hypentelium nigricans*, *Semotilus a. atromaculatus*, *Notropis blennius*, *Notemigonus crysoleucas auratus*, *Hybognathus hankinsoni*, *Campostoma anomalum pullum*, *Lepomis cyanellus*, *L. humilis*, *Hadropterus maculatus*, *H. phoxocephalus*, *Ammocrypta clara*, and *Poecilichthys flabellaris lineolatus*. Several additional species in the area were not represented in catfish stomachs or in the enumerated random seining.

[3]Less than 0.5 percent.

forms to, catfish, either in deep water (*Notropis cornutus frontalis* and *Ceratichthys perspicuus*) or close to the bottom (*Notropis d. dorsalis*), where large catfish do much of their feeding. Conversely, *N. spilopterus,* which is especially abundant in shallow water, might thereby be partially isolated from predation. However, in view of the small sample size of stomach specimens and the necessarily approximate determination of forage-fish percentages, these deviations are perhaps insignificant.

Young catfish make up 2 percent of the small fish population in the random sampling and comprise 2 percent of the fish found in stomachs. It appears that cannibalism is practiced in direct proportion to the relative abundance of young catfish and other small fish. Young game fish of species other than channel catfish are rare in the study area, and none was encountered in the stomach analyses.

Feeding Behavior and its Relationship to Certain Extrinsic Factors

Feeding behavior in the channel catfish is modified or controlled by several, or perhaps many, functional and structural adaptations. These adjusting mechanisms display complex interrelationships, and in a field study such as this the control of variables has not been possible; hence, recognition of the responses to simple environmental stimuli is not clear. There have been raised in our minds many interesting problems to which controlled experimentation could provide answers. What role does light intensity play in the initiation or inhibition of feeding? Of what importance is vision in the capture of food organisms? What are the comparative values of scent and taste in the location of food? Is there a minimum temperature below which feeding ceases, and what is the relationship between temperature and food demand? Is the apparent preference of the channel catfish for life in flowing water the result of feeding adaptions? These and other questions seem to provide profitable subjects for investigation.

In prairie streams it is rarely possible to dissociate the environmental factors of turbidity and water level: high water levels accompany high turbidity; low water levels are periods of reduced turbidity. Decrease in water level concentrates the available food organisms, and greater clarity of water makes them more vulnerable to predators which feed by sight. It is debatable whether channel catfish utilize vision in feeding, but the relatively large eyes (for an ameiurid) may be assumed to have functional significance. The water level during the first half of September 1941 (when most of our sample for the month was secured) was the lowest during the period of study, and the turbidity was greatly reduced. Legal fish taken in the month had eaten an average of 3.5 forage fish, in contrast to 0.7 in August and 0.5 in July—months of higher water level and increased turbidity. Concentration of forage fish plus improved conditions of

visibility clearly permit more effective predation on free-swimming prey.

The ameiurids are essentially nocturnal, and all (except, perhaps, the blind subterranean species) are most active and probably do most of their feeding at night, despite the fact that channel catfish can occasionally be taken on hook and line at any hour of the day. On several occasions we fished with numerous baited hooks (see p. 118) continuously from dusk until dawn. Fish taken at or shortly after dark frequently had empty stomachs, but those taken later usually were at least partially full. The hourly catches from dusk until shortly after midnight were roughly twice as heavy as those preceding dawn. The difference was so marked that we eventually gave up fishing after about 2 a.m. because of the low return. We believe that the reduced catch reflects early appetite satiation of a large portion of the population. If food is scarce, feeding might be expected to continue throughout the night or into daylight. The stomachs of catfish seined in the forenoon usually contain food which is in an early stage of digestion, whereas those taken in the afternoon most often are empty or have food which is in an advanced stage of decomposition. Our data are inadequate to determine the effects of bright moonlight nights or dull, overcast weather on daily feeding trends. But evidence secured by the junior author in 1946 indicates that bright moonlight during periods of relatively clear water has an inhibiting effect on nocturnal feeding of channel catfish. At times of turbid water, however, normal night feeding is apparently not modified.

Within the limits available for analysis from this study, no temperature thresholds which restrict digestion or feeding are apparent. Fish were caught at water temperatures between 50° F. and 94° F., and there is no sharp correlation between temperature and quantity of food contained in the stomach. At temperatures in excess of 90° F. 64 percent of the fish taken have the stomach at least one-fourth filled with food. Some 54 percent of the fish taken at temperatures between 50°and 60° F. have the stomach equally full. It is probable that there is a minimum threshold, perhaps between 40° and 50° F., below which channel catfish eat little or not at all. Only 2 of 17 large catfish taken in the Des Moines River at Fraser, on February 10, 1940, contain food; one has a caddis fly larva, the other a small quantity of green algae—the intestines of all specimens are empty. At the time, the river was frozen except in a pool beneath a low dam where the fish were seined. The water temperature was 32° F.

Food intake is apparently nonexistent, or sharply curtailed, in adult channel catfish during the breeding period. A single large male removed from a burrow while guarding his nest was found to have an empty stomach. Information obtained from commercial fishermen on the Mississippi River indicates that baited traps are widely used and highly effective in taking catfish during spring prior to the breeding season (June), and again after early July. But this same gear is

ineffective when the fish are spawning. In June, adult catfish are substituted in the traps for the customary cheese-scrap bait. A trap "baited" with a male catfish will, we are told, catch females almost exclusively, but if a female is provided as a lure the take consists largely of males. Why after one fish of the opposite sex is entrapped the additional fish are not attracted irrespective of sex we were not informed. Nevertheless fishermen who persist in using food-baits catch few if any catfish during the breeding season. We take this fact as strongly suggestive evidence to indicate a temporary cessation from feeding.

Management Considerations

No attempt is made here to outline a program for the management of the channel catfish in the Des Moines River or other comparable streams, since the limiting factors are usually not known, and probably vary from year to year and from stream to stream. Yet certain conclusions, drawn from this study and general experience gained in Iowa over a period of several years, seem justified.

In moderate-sized to large prairie rivers, such as the Des Moines, natural reproduction and early survival are usually attended by high success in years of normal water level. (We have some evidence to indicate that severe floods during the early and middle part of the summer result either in poor reproduction or low survival of the young fish.) It appears, then, that production of a large number of legal-sized catfish depends chiefly on favorable shelter conditions and an adequate food supply.

Neither of these essentials is met by long, straight stretches of stream of monotonously uniform depth and with a bottom of shifting sand. Yet precisely these conditions obtain along untold miles of our prairie rivers. Diversity of environment is needed to supply the catfish with the requisites for maximum production. Suitable shelter may take the form of deep pools, lateral lagoons and backwaters (especially valuable for retreat in time of flood), or protected sites such as those offered by old stumps, submerged logs, drift jams, and boulders. Food production is highest in quiet protected areas, in masses of floating or submerged debris, and on rock riffles. In addition, the presence of bushes and trees overhanging the stream adds measurably to the supply of terrestrial insects.

Under existing conditions of intensive land use, with the attendant soil erosion and drainage, material improvement of conditions may appear to be impractical. But improvement for fishing is not the only stake—other recreational and aesthetic values of our watercourses are intertwined with the need of the agriculturist for the preservation of his uplands from denudation and of his bottomlands from bank erosion and flooding. Soil conservation is making great strides, pollution abatement is progresing rapidly in Iowa (Speaker and Bailey, 1945), and there are positive measures which can be taken to improve habitat conditions in and adjacent to the streams.

Masses of branches, logs, and half-submerged trees (see Fig. 4) which occasionaly accumulate along the banks prove to be favored shelters for catfish, and perhaps the richest areas of food production. Typically these drift jams owe their origin to trees which have been undercut by floods and felled into the stream. They may persist for years, but are commonly washed away by succeeding floods. Since they are characteristically located along eroding banks, maintenance of their position serves the additional function of shore protection. Anchoring of such trees (perhaps by means of cables, attached either before or after felling) appeals to us as a simple, inexpensive method of environmental improvement. Many of the constructions now in use for the improvement of trout streams (Hubbs, Greeley, and Tarzwell, 1933) might be adapted for use in small catfish rivers. Bank protection, achieved through plantings and elimination of streamside grazing, is another method of improvement which should prove practical on an extensive scale.

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A SUMMARY OF EXPERIMENTS IN MICHIGAN LAKES ON THE ELIMINATION OF FISH POPULATIONS WITH ROTENONE, 1934-1942[1]

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ABSTRACT

During the period 1934-1942, 32 lakes in Michigan were treated with rotenone to remove or reduce unwanted fish populations, and an attempt to recover the entire fish population was made on 18 of them. The majority of these lakes were not supporting a desirable or normally growing fish population at the time they were treated. They were mostly small, all less than 22 acres, and included lakes whose waters ranged from very soft to very hard, from acid to alkaline, and from shallow to very deep.

In productivity, as measured by the standing crop of fish recovered, these lakes ranged from 10.0 to 194.5 pounds per acre. The lakes averaged 58.5 pounds of fish per acre of which 18.2 pounds were legal-sized game fish.

The hard-water lakes were, in general, more productive than the soft-water lakes and the warm-water lakes more productive than the trout lakes.

For centuries, natives of tropical regions have employed drugs of vegetable origin to kill or stun fish. Of comparatively recent origin, however, is the discovery that rotenone and other similar components of derris and cubé roots constitute valuable management tools for the elimination of undesirable fish populations in inland waters. So far as can be determined by the writer the first such application of these drugs was made by the Michigan Conservation Department's Institute for Fisheries Research on July 17 and 23, 1934, when two small ponds on the estate of Mr. W. O. Briggs at Birmingham, Michigan, were treated for the removal of a heavy carp population. Lacking any precedent for determining concentrations required, these pioneer workers used relatively weak concentrations of between 0.04 and 0.09 p.p.m. of rotenone. Many fish were killed, but some survived the poisoning in both ponds. Later investigations (Leonard, 1939, and others) have shown that a concentration of at least 0.5 p.p.m. of derris or cubé root of 5-percent rotenone content is required to insure a complete kill, and Brown and Ball (1942) have demonstrated that this concentration is ineffective at temperatures below 48° F.

Since the first experimental use of rotenone, 32 lakes in Michigan have been treated to remove or reduce the fish population.

It is the purpose of this report to set fourth, in tabular form, the data that have been gathered during the period 1934-1942 on Michigan lakes treated with rotenone. Treatments of some of these lakes

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TABLE 1.—*Number and weight of fish according to species recovered from Michigan lakes treated with rotenone.*
[Upper figure in species column is number of fish and lower figure is weight in pounds of fish recovered]

Name of lake	County	Area (acres)	Date of poisoning	Total pounds of fish	Total number of fish	Black bass[1]	Rock bass	Bluegill	Pumpkin-seeds	Yellow perch	Trout[2]	Minnows	Other fish[3]	Number per acre and pounds per acre
South Twin[4]	Otsego	4.3	9/20/34	....	....	......	......	......	......	4,118	......	......	......	......
						......	......	......	......	125	......	......	......	......
Ford	do.	10.7	9/9/36	521	41,703	......	......	......	......	4,836	27	36,840	......	3,564
						......	......	......	......	353	7	161	......	44
Clear[5]	Alcona	11.3	8/26/37	2,197	25,147	......	......	2,695	10,106	......	......	5,143	7,203	2,225
						......	......	56	452	......	......	24	1,863	195
Booth	Otsego	16.0	9/6/37	349	20,192	......	1,233	......	......	4,827	......	14,054	78	1,262
						......	53	......	......	146	......	63	86	22
Howe	Crawford	13.4	9/7/37	509	23,528	18,759	......	......	775	283	......	1,118	50	1,755
						155	......	......	27	14	......	6	313	38
Walsh[4]	Washtenaw	10.2	4/25/38	943	6,267	484	......	3,271	300	144	......	837	1,231	614
						154	......	579	30	21	......	7	152	92
Pike Number 4	Oscoda	4.6	8/6/39	204	13,368	371	663	......	1,541	7,543	......	3,131	146	2,904
						22	16	......	30	65	......	9	62	44
O'Brien[4]	Alcona	10.4	8/9/39	282	31,643	2	1,013	......	1,556	2,264	2	26,399	407	3,043
						2	39	......	13	12	11	64	141	27
Pond Number 4	Otsego	1.6	8/15/39	181	3,336	173	688	......	4	241	5	1,984	271	210
						13	42	......	0	29	2	25	70	113
Fitzek[4]	do.	6.2	8/15/39	119	5,716	147	632	......	......	398	12	4,487	40	921
						26	37	......	......	28	1	16	12	19
Airport	Marquette	6.8	8/20/40	97	1,281	......	......	......	......	1,232	49	......	......	188
						......	......	......	......	92	5	......	......	15
Linnbeck[6]	Menominee	5.1	9/11/40	146	22,521	29	24	......	1,142	3,000	......	18,118	208	4,416
						1	6	......	13	34	......	64	28	29
Swanzy	Marquette	20.3	9/11/40	630	10,588	241	......	319	......	8,756	......	1,272	......	521
						67	......	41	......	495	......	28	......	31
Third Sister	Washtenaw	10.0	5/6/41	867	15,454	470	......	4,057	610	......	......	8,443	1,874	1,545
						127	......	537	29	......	......	30	144	87
DeBruin's	Kalamazoo	0.8	5/27/41	241	9,755	......	......	......	4,200	......	......	400	5,155	1,219
						......	......	......	65	......	......	3	173	301
Twin	Marquette	21.5	7/23/41	215	7,699	109	......	......	......	6,600	......	990	......	358
						70	......	......	......	123	......	22	......	10
East Fish	Montmorency	13.5	8/25/41	405	7,693	......	......	......	......	5,237	160	1,683	613	566
						......	......	......	......	253	15	30	108	30
North Basin Twin	Oscoda	7.8	8/29/41	539	9,224	164	......	7,672	281	......	......	[7]985	122	1,183
						43	......	446	23	......	......	6	21	69
Kimes Number 3	Newaygo	6.8	9/5/41	934	35,202	774	......	7,949	......	847	......	24,685	1,560	5,176
						129	......	472	......	48	......	33	253	137
Holland	Luce	5.3	9/10/41	435	....	......	......	......	2,491	1	86	no count	552	no total
						......	......	......	78	0	6	147	204	82
Deep	Oakland	14.8	9/12/41	563	27,329	785	585	16,059	5,935	817	......	......	3,144	1,847
						106	23	256	69	20	......	......	89	38
Burke	Clinton	1.8	9/1/42	108	1,038	201	......	354	73	2	......	......	408	577
						17	......	39	4	0	......	......	45	60

[1]Largemouth and smallmouth black bass
[2]Brook, brown, and rainbow trout
[3]Carp, goldfish, green sunfish, chub sucker, bullhead
[4]Incomplete kill
[5]Weights based on random sample
[6]Pick-up not complete—probably all legal-sized fish recovered
[7][illegible]

have been the subject of formal reports (Eschmeyer, 1937, 1938a, 1938b, 1938c, 1939; Leonard, 1939; Greenbank, 1941; Beckman, 1941; Brown and Ball, 1943a, 1943b; Krumholz, 1944). Others have been recorded only as reports to the Michigan Department of Conservation, and still others are first recorded here.

No attempt has been made to break the material down into detailed analyses of growth rates and size and age groups within the species composition. That these waters are not, as a group, typical of the inland lakes of Michigan is evidenced by the fact that most of them were treated with rotenone to eliminate the population present so that a different and presumably better one could be introduced. Four of the lakes were treated for other reasons: Walsh Lake was poisoned to eliminate a population of fish which, although growing well, was so heavily parasitized as to be unappetizing; Howe Lake had a normally growing population but removal of the carp appeared desirable; Third Sister Lake and Deep Lake were treated as part of long-range experimental programs.

Of the 32 lakes subjected to rotenone treatment, only 18 have been recorded as having a complete kill and subsequent recovery of the entire population. In many of the lakes treated it was not feasible to attempt collection of the dead fish due to the physiography of the lake shore and bottom. Named in Table 1 are the lakes which have been poisoned, together with their location and size; tabulated also are the total weight and number of each fish species recovered. Not included here are nine lakes on which no effort to recover fish was made, or on which at most only a partial recovery was attempted.

Table 2 contains a summary of data for lakes in which a complete, or nearly complete, kill was made. For these lakes the area, depth, pH, methyl-orange alkalinity, presence or absence of thermocline, total weight, and number of fish recovered per acre, and number and weight of legal game fish per acre are recorded. Included are representatives of nearly every type of lake found in Michigan with the exception of the large lake trout-cisco lakes. They vary in size from less than 1 acre to 22 acres and in depth from 9 to 90 feet. The pH range is from acid to quite alkaline; the methyl-orange alkalinity range is wide, from 5 to 240 p.p.m. Geographically they are spread from southern Michigan to the northern part of the Upper Peninsula. In productivity as measured by the standing crop of fish recovered they range from 10.0 to 194.5 pounds per acre.

The total number of fish and number per acre as recorded in Tables 1 and 2 probably have little significance as it was not possible, in many lakes, to recover the entire minnow population. It is possible that a large proportion of the young-of-the-year fish were not recovered, as the first-year fish disintegrated in some lakes within a very short time following death. This age group would have a considerable effect upon the total numbers of fish but relatively little on the total weight.

TABLE 2.—*A summary of limnological data and recovery of fish from Michigan lakes in which a complete kill and recovery was obtained*

Name of lake	County	Area (acres)	Maximum depth (feet)	pH	Methyl-orange alkalinity	Depth of thermo-cline (feet)	Type of lake	Total fish per acre Number	Total fish per acre (pounds)	Legal-sized game fish per acre Number	Legal-sized game fish per acre (pounds)
Ford	Otsego	10.7	33	8.2	127	15-18	Trout	3,897	44.1	85	8.8
Clear	Alcona	11.3	9	Alkaline	165	None	Bass	2,225	194.5	6	0.7
Booth	Otsego	16.0	31	7.9-8.2	125	None	Bass	1,262	21.8	3	0.3
Howe	Crawford	13.4	24	7.5-8.1	51	None	Bass	1,755	38.0	10	7.0
Walsh[1]	Washtenaw	10.2	20	Alkaline	131-145	None	Bass	614	92.4	167	78.9
Pike Number 4	Oscoda	4.6	18	Alkaline	148-157	None	Trout	2,904	44.3	79	14.7
O'Brien	Alcona	10.3	30	Alkaline	162-172	?	Trout	3,043	27.1	6	5.1
Airport	Marquette	6.7	28	5.4-6.2	5	12-21	Trout	188	14.3	99	9.5
Linnbeck	Menominee	5.1	25	7.6-8.4	168-211	9-15	Trout	4,416	28.5	20	5.2
Swanzy	Marquette	20.4	45	6.8-7.4	15-24	15-27	Trout	522	31.0	67	11.1
Third Sister	Washtenaw	10.0	60	6.8-7.6	85-95	12-18	Bass	1,545	86.7	170	69.6
Twin	Marquette	21.9	90	5.6-6.8	5	12-30	Trout	358	10.0	19	2.4
East Fish	Montmorency	13.5	42	7.8-8.0	190-202	15-30	Trout	565	30.0	36	4.0
North Basin Twin	Oscoda	7.8	60	7.0-8.4	66-76	15-24	Trout	1,183	69.1	42	9.9
Kimes Number 3	Newaygo	6.8	18	8.1-8.6	170	None	Trout	5,176	137.3	254	57.0
Holland	Luce	5.3	22	7.2-7.4	18-23	15-22	Trout	......	82.0	[2]0	[2]0
Deep	Oakland	14.8	61	6.8-8.4	78-108	15-27	Trout	1,847	38.0	58	21.2
Burke	Clinton	1.8	39	6.8-8.5	175-240	15-25	Trout	1,038	60.1	104	22.9

[1]Not a complete kill

[2]Only two legal fish in lake

In Table 3, the lakes for which a complete, or nearly complete, kill is recorded have been arranged according to hardness of the water. Three divisions have been made: soft (below 50 p.p.m. methyl-orange alkalinity); intermediate (methyl-orange alkalinity, 50-150 p.p.m.); and hard (above 150 p.p.m. methyl orange alkalinity). On this basis there appears to be a positive correlation between alkalinity and fish production. The lakes listed as hard-water lakes have an average poundage per acre that is higher than for either of the other groups. There is, however, considerable individual variation in productivity of the lakes in all categories, and other factors that were not considered in these studies may well influence the data.

TABLE 3.—*Data on lakes in which complete recovery of poisoned fish was attempted*
[Arranged according to hardness of water]

Name of lake, county, and region	Area (acres)	Methyl-orange alkalinity	Type of lake (fish)	Pounds per acre
Soft-water lakes—methyl-orange alkalinity, 50 p.p.m. Grand average pounds of fisth per acre, 28.0				
Airport, Marquette, I	6.8	5	Trout	14.5
Swanzy, Marquette, I	20.4	15-24	Trout	31.0
Witch Twin, Marquette, I	21.5	5	Trout	10.0
Holland, Luce, I	5.3	18-23	Trout	82.0
Howe, Crawford, II	13.4	44-51	Bass	38.0
Intermediate lakes—methyl-orange alkalinity, 50-150 p.p.m. Grand average pounds of fish per acre, 53.6				
North Basin Twin, Oscoda, II	7.8	66-76	Trout	69.1
Third Sister, Washtenaw, III	10.0	88-90	Bass	86.7
Deep, Oakland, III	14.8	78-108	Trout	38.0
Ford, Otsego, II	10.7	127	Trout	44.1
Booth, Otsego, II	16.0	125	Bass	21.8
Walsh, Washtenaw, III	10.2	131-145	Bass	92.4
Hard-water lakes—methyl-orange alkalinity, 150 p.p.m. Grand average pounds of fish per acre, 74.2				
Clear, Alcona, II	11.3	165	Bass	194.5
Pike Number 4, Oscoda, II	4.6	148-157	Trout	44.3
O'Brien, Alcona, II	10.3	162-172	Trout	27.1
Linnbeck, Menominee, I	5.1	168-211	Trout	28.5
Kimes, Newaygo, II	6.8	170	Trout	137.3
Burke, Clinton, III	1.8	175-240	Trout	60.1
East Fish, Montmorency, II	13.5	190-202	Trout	30.0

The region in which each lake is located is recorded in the table to show its general geographical location. These regions are operational areas of the Fish Division of the Conservation Department and are located as shown on the accompanying map (Fig. 1).

The lakes were divided also into two categories, "trout" and "bass," on the basis of their ability to support trout or only warm-water fish. Third Sister Lake, here classified as a "bass" lake, is actually a marginal trout lake. A comparison of productivity of the 18 lakes on this basis, shown in Table 4, indicates that the "bass" lakes are considerably more productive than the "trout" lakes.

Because of the long period covered by this report and the fact that the data were collected and recorded by several workers in a non-uniform manner, no definite comparisons and conclusions can be drawn. The data do show, nevertheless, the very considerable differences in productivity of fish, as measured by the recovery of fish

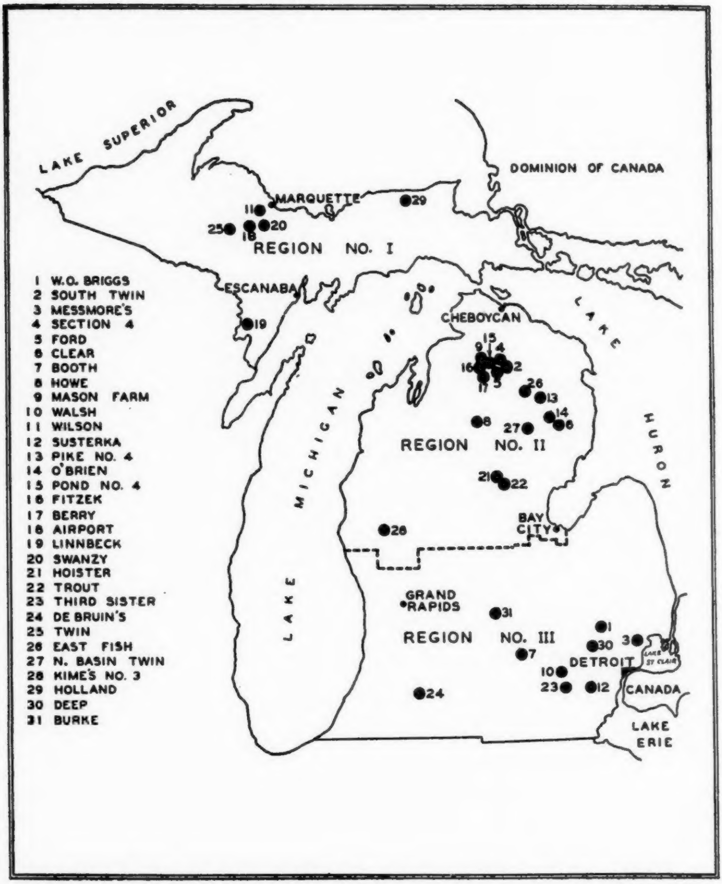

FIGURE 1.—Location of Michigan lakes treated with rotenone, 1934-1942.

following poisoning, found in the smaller lakes of the state, and that no one index of productivity, as measured on these lakes, appears to point to the reason for the differences.

TABLE 4.—*Comparison of total pounds and pounds of legal-sized fish per acre in "bass-" and "trout-type" lakes.*

Type of lake	Total pounds of fish per acre	Pounds of legal-sized fish per acre
Trout	47.7	13.2
Bass	81.3	31.3

To summarize the data briefly: The average size of the lakes having a complete pick-up was 10.6 acres; the lakes averaged 58.5 pounds of fish per acre of which 18.2 pounds were legal-sized game fish. The average total number of fish in the lakes is not believed to be a reliable figure due to difficulties of recovering small fish and minnows, but the average of 68 legal game fish per acre is probably a close approximation of the population of legal-sized fish.

When considering the total fish production of these lakes it is well to note that the counts and weights were made on *recovered* fish and definite evidence is lacking that would determine whether all, or only part, of the fish killed were recovered. It is possible that some of the fish may go to the bottom in deep water and never be recovered.

Twelve of the lakes listed as having a complete kill were trout lakes and six were warm-water lakes. Following removal of their undesirable populations, the 12 lakes were planted with trout from state fish hatcheries and the use of live minnows as bait prohibited. To date, six of these lakes are known to have been repopulated with warm-water fish, three contain only trout, and the records are incomplete for three. Ineffective barrier dams on outlets, incomplete poisoning or the release of unused bait may explain repopulation.

The fact that half of the lakes that were to be managed for trout have only warm-water species present, and the evidence that in many of the other lakes undesirable species have been introduced, points out that in the rehabilitation of lakes the task is only partly completed when the unwanted population has been removed. Considerable effort will have to be made in the future to safeguard against the introduction of unwanted species if the removal of fish is to be a worth-while and economical undertaking.

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SURVIVAL AND GROWTH OF FINGERLING BROWN TROUT (*SALMO FARIO*) REARED UNDER DIFFERENT HATCHERY CONDITIONS AND PLANTED IN FAST AND SLOW WATER[1]

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Abstract

Data obtained on Crystal Creek, New York, relative to the effectiveness of planting brown trout in slow and in fast water are presented. Of three plantings of fingerlings made throughout the length of the stream, annual electrical inventories showed a significantly greater number of fish present in fast-water sections than in slow-water sections. Of the June 1940 planting, 20.2 trout per fast-water section and 10.1 per slow-water section were found after 3 months; of the September 1941 planting, 6.8 per fast-water section and 2.6 per slow-water section were recovered after one year; of the October 1940 planting, 1.00 per fast-water section and 0.62 per slow-water section were taken after one year.

In other experiments over a summer period only, where fish were planted in screened-off areas of fast or slow water, inventories after short periods of time also showed the survival to be greater in fast water. Of two plantings in each water type, after 4 weeks there were 2.2 times as many fish surviving in the fast water as in the slow water. Growth rates of planted brown trout in both series of experiments were also greater in fast water.

One experiment was designed to measure the effect of rearing trout in the hatcheries on a diet composed of meat and dry foods as contrasted to a diet of straight meat. The criteria employed were relative survival and growth rates after planting of trout reared under these conditions. No differences in the survival or growth associated with hatchery diets could be found. The amount of data available for this test was limited, however.

Differences in survival and growth of successive plantings made in the same sections of stream indicate the variability of stocking results and suggest the necessity of valuating further the effects of various hatchery procedures and stocking methods upon the success of plantings.

Introduction

Recent data seem to indicate that, in general, the survival of hatchery-reared fingerling trout planted in natural waters is of a rather low order, and it is obvious that any modifications in hatchery methods or in planting technique which would increase the survival would be of considerable importance. Varying the methods of spawn-taking, rearing, feeding, transporting, and stocking all seem to offer possibilities of increasing the efficiency of hatchery operations and it would appear that the effects of such modifications would best be evaluated on the basis of survival, growth, etc., of the fish after they have been planted.

[1]Presented by title at the Seventy-sixth Annual Meeting.

Some information is available from a 4-year study of the trout of Crystal Creek, New York, concerning the relative effectiveness of planting brown trout in slow and fast water and a small amount of information is at hand concerning the possible effect that rearing trout on various diets and in different types of water supply might have upon their survival and growth after planting.

There were five plantings of marked hatchery brown trout fingerlings that apply to this study during the investigation on Crystal Creek.[2] Of these, three were made over the 4.17 miles of stream length and the estimate of the relative survival and growth of fish of these plantings was made on the basis of four yearly (September) inventories of 13 sample sections, by the method of electrical shocking (Haskell, 1940; Haskell and Zilliox, 1941). Of these 13 sections, 8 were slow-water and 5 were fast-water sections.

The other two plantings were each made in four separate, segregated, screened-off areas of which two were fast-water and two were slow-water areas. The relative survival and growth in these experiments were evaluated by several electrical inventories all made over a relatively short span of time (2 months). The two types of experiments, that is, long- and short-term, will be discussed separately as regards survival and growth in slow and fast water.

Abundance and Growth of Brown Trout Recovered in Fast and Slow Water — Long-term Experiments

The three plantings, with two in the fall seasons and one in early summer, were each distributed more or less uniformly over the whole 4.17 miles of stream and the fish were free to move about at their own discretion. The method of inventory of each of the 13 sample sections each September has been presented (Schuck, 1945) and the details will not be repeated here. As it applies to estimating the relative survival of these hatchery plantings in fast and slow water, the numbers of fish in a certain planting that were actually recovered in the five fast-water sections were compared with the numbers recovered in the eight slow-water sections.

With regard to growth determination, each lot of fish had been marked by the removal of various fins or the maxillary bones; thus only group identification and no individual recognition was possible. At the time of the planting the average weight of each lot was recorded and the average total length was estimated from the length-weight relationship of hatchery trout as given by Deuel, Haskell, and Tunison (1942). During the annual inventories, the length of each individual recovered in the fast- and in the slow-water sections was recorded.

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[2]The authors are indebted to the following staff members of the Crystal Creek Fishery Investigation who aided in the accumulation of the data over the 1939-1942 period: D. G. Pasko, R. G. Zilliox, C. Heacox, A. C. Petty, J. J. Porter, S. L. Crump, D. R. Embody, Dr. H. J. Rayner, J. A. Tihen, E. Haskell and T. Foote.

Survival: June 1940 planting.—In June 1940, 5,300 brown trout averaging 6.3 centimeters ($2\frac{1}{2}$ inches) and marked by the removal of the left ventral fin were planted throughout the stream. The inventory of September 1940, after 3 months, showed 182 fish in the 13 sections or an estimated 2,720 in the whole stream after correction for the efficiency of the electrical method of collecting trout of this size. An average of 10.1 were found per slow-water section and an average of 20.2 per fast-water section.

The inventory of the following September (1941) produced a total of only one fish in the 13 sections, but considerable regeneration probably caused many more of the planted fish to go unrecognized at this time (15 months after planting).

Survival: September 1941 planting.—In September 1941, 6,300 brown trout averaging 9.5 centimeters (3.7 inches) and marked by the removal of the adipose fin and right or left maxillary bone were planted throughout the whole stream in a very uniform manner, one to about 3.5 feet. An average of 2.6 were found after a year in the slow-water sections as compared to 6.8 per fast-water section. The total estimated figure for the whole stream was 398 fish, or a 6.3-percent survival over the period of 1 year. No regeneration occurred over this period.

Survival: October 1940 planting.—In October 1940, 2,200 brown trout averaging 10.2 centimeters (4.0 inches) and marked by the removal of the right or left maxillary bone were planted throughout the stream length, but were distributed more heavily in the 13 sample sections than elsewhere. The inventory in 1941 showed an average of 0.62 fish per slow-water section as compared to 1.00 per fast-water section. No fish are thought to have been missed because of regeneration of the maxillary bone.

Survival: all plantings combined.—Summarizing these three experiments with respect to survival—13.32 fish were found after intervals of 3 to 12 months per slow-water section as contrasted to 29.00 per fast-water section. This difference was found to be statistically significant.

Growth: June 1940 planting.—The 5,300 brown trout averaged 6.30 centimeters in total length when planted. After 3 months, those recovered in the slow-water section averaged 9.03 centimeters and those in the fast-water sections, 9.59 centimeters. This difference, although a slight one, was found to be statistically significant by the analysis of variance (Snedecor, 1940). A large number of fish (182) was available for this analysis.

Growth: September 1941 planting.—The 6,300 brown trout averaged 9.50 centimeters in length when planted and after a year those recovered in the slow water averaged 15.3 and those in the fast water averaged 15.2 centimeters.

Growth: October 1940 planting.—The average gain of five fish recovered in slow water was 4.82 centimeters as compared to 4.84

centimeters for five fish recovered in fast water.

Growth: all plantings combined.—The weighted average gain of all fish recovered in slow water in these three experiments was 3.43 centimeters and the average of all fish recovered in fast water sections was 3.93 centimeters.

Abundance and Growth of Brown Trout Recovered in Fast and Slow Water — Short-term Experiments

These plantings were made in the summer of 1941 to produce detailed information on survival and growth over a short summer period during which time stream conditions were thought to be relatively unfavorable for trout. Plantings of 408 fish averaging 2.9 inches and 236 fish averaging 2.8 inches were made on July 14 and August 1, 1941, respectively, in four areas, A, B, C, and D (Tables 1 and 2). These four areas were segregated from one another and from the rest of Crystal Creek by five weirs of quarter-inch wire mesh screening. Areas A and D were slow-water areas; B and C were fast-water areas. Data on survival and growth of these fish after various periods of time were obtained by special population inventories similar to the annual inventories used on the 13 sections, but carried out on (1) August 11-14, (2) August 19-22, (3) August 28-31, and (4) September 3-5. The numbers planted and the numbers estimated to be present at the August inventory dates are shown on Table 1 (July 14 planting) and Table 2 (August 1 planting).

Table 1.—*Numbers of fingerling brown trout planted July 14, 1941, in the four segregated areas of Crystal Creek, New York, and the numbers at three inventory dates.*

Area	Length of area (feet)	Number planted	Numbers present August 11-14	August 19-22	August 28-31
A (slow)	665	189	54	40	26
D (slow)	164	46	8	4	4
B (fast)	317	90	34	29	21
C (fast)	292	83	37	32	24
Total	1,438	408	133	105	75

Table 2.—*Numbers of fingerling brown trout planted August 1, 1941, in the four segregated areas of Crystal Creek, New York, and the numbers remaining at three inventory dates.*

Area	Length of area (feet)	Number planted	Numbers present August 11-14	August 19-22	August 28-31
A (slow)	665	111	23	16	11
D (slow)	164	26	5	4	2
B (fast)	317	52	27	22	19
C (fast)	292	47	13	11	6
Total	1,438	236	68	53	38

Survival: July 14, 1941, planting.—Of the 235 brown trout planted in the two slow-water areas (A and D), 62 were present on August 11-14, 44 on August 19-22, and 30 on August 28-31 (Table 1). These figures represent survival of 26.4 percent, 18.7 percent, and 12.8

percent to the dates mentioned. In contrast, of 173 planted in fast-water areas (B and C), 71 or 41.0 percent, 61 or 35.3 percent, and 45 or 26.0 percent survived to the same inventory dates.

Survival: August 1, 1941, planting.—A similar comparison of survivals of the August 1 planting (total of 236 brown trout) in fast- and slow-water areas (Table 2) shows survival as follows: 20.4 percent in slow water and 40.4 percent in fast water at the first inventory; 14.6 percent in slow water and 33.3 percent in fast water at the second inventory; and 9.5 percent in slow water and 25.3 percent in fast water at the third inventory.

Survival: both plantings combined.—For both plantings combined, the survivals were: 24.2 percent present in the slow-water areas and 40.8 percent in the fast-water areas at the first inventory; 17.2 percent in slow water and 34.6 percent in fast water at the second inventory; and 11.6 percent in slow water and 25.7 percent in fast water at the

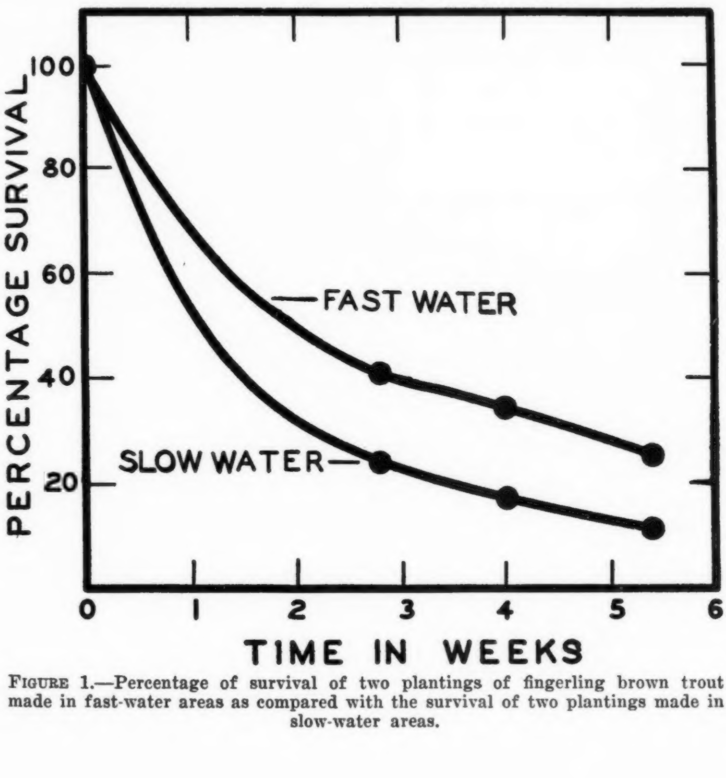

FIGURE 1.—Percentage of survival of two plantings of fingerling brown trout made in fast-water areas as compared with the survival of two plantings made in slow-water areas.

third inventory. This comparison of the overall relative survival in the two fast-water areas and the two slow-water areas is shown in Figure 1. Values for "time in weeks" are unweighted averages for the two plantings to the dates of inventory.

Growth: July 14 planting.—The 235 fish stocked in the two slow-water areas averaged 4.52 grams in weight and the 173 stocked in the two fast-water areas averaged 4.78 grams when planted. A summary of the weights that the fish attained in fast- and slow-water areas at the several inventory dates is shown in Table 3. A slightly greater and more consistent gain is indicated for the fast-water fish.

Growth: August 1 planting.—These fish showed great fluctuations in weight and did not show a gain after a month in the stream. The average weights for the two types of water are shown in Table 4.

TABLE 3.—*Average weights at planting and average weights on recovery after varying periods of time for fingerling brown trout.*
[Stocked on July 14, 1941, in screened-off fast- and slow water areas of Crystal Creek, New York]

Time (weeks)	Slow-water areas		Fast-water areas	
	Number of fish	Weight (grams)	Number of fish	Weight (grams)
[1]0.0	235	4.52	173	4.78
4.1	29	4.49	46	5.28
5.3	27	4.75	48	5.68
6.7	18	4.58	40	6.52
7.4	8	6.22	21	6.89

[1]Time of planting

Growth: both plantings combined.—A graphical representation of the growth of the July 14 and August 1 plantings combined in the fast-water and in the slow-water areas is shown in Figure 2. Values for "time in weeks" are unweighted averages of the two plantings to the date of the first (August 11-14), second (August 19-22), third (August 28-31), and fourth (September 3-5) inventories. Averages for "weights in grams" are weighted averages for recoveries from the two plantings at the time of the several inventories.

TABLE 4.—*Average weights at planting and average weights on recovery after varying periods of time for fingerling brown trout.*
[Stocked on August 1, 1941, in screened-off fast and slow-water areas of Crystal Creek, New York]

Time (weeks)	Slow-water areas		Fast-water areas	
	Number of fish	Weight (grams)	Number of fish	Weight (grams)
[1]0.0	137	3.89	99	4.08
1.4	7	4.06	17	3.37
2.7	15	3.69	20	4.04
4.0	9	3.33	20	3.95
4.7	5	3.50	14	4.06

[1]Time of planting

DIFFERENCES IN SURVIVAL AND GROWTH OF TWO SUCCESSIVE PLANTINGS

Table 5 shows the percentage survival of the brown trout planted July 14, at 4 weeks, 5.3 weeks and 6.7 weeks following planting and the survival for those fish planted August 1 at the end of 1.4 weeks,

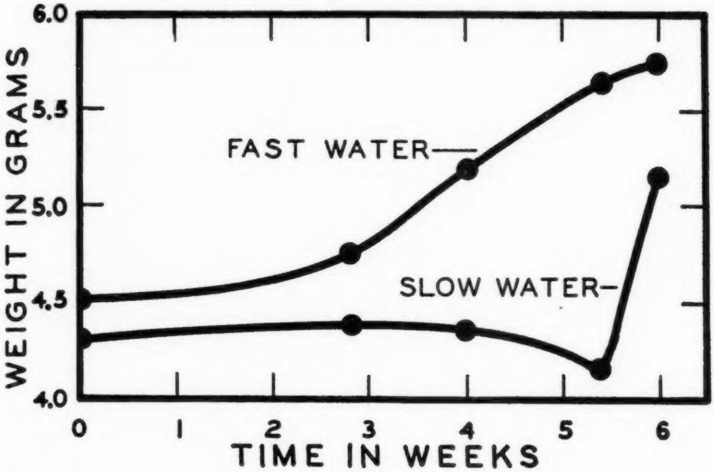

FIGURE 2.—Average weights at planting and average weights on recovery after varying periods of time for two plantings of fingerling brown trout in screened-off fast- and slow-water areas of Crystal Creek, New York.

TABLE 5.—*Relative survival of brown trout of the two plantings in screened-off fast- and slow-water areas of Crystal Creek, New York, to the three inventory dates.*

Date[1]	July 14 planting		August 1 planting	
	Time weeks)	Percentage survival	Time (weeks)	Percentage survival
July 14	0	100.0	....	....
August 1	....	....	0	100.0
August 11-14	4.1	32.6	1.4	28.8
August 19-22	5.3	25.7	2.7	23.7
August 28 31	6.7	18.4	4.0	16.1

[1]First two dates are dates of planting

2.7 weeks and 4.0 weeks. It can be seen that the relative survival of the fish planted on July 14 was considerably greater.

The brown trout planted on July 14 showed a consistent gain in weight throughout the experiment, and grew from an average of 4.61 grams to an average of 6.71 grams by the end of 7.4 weeks. The fish planted August 1 were highly variable and actually showed a loss at the end of 4.7 weeks.

EFFECT OF DIETS ON SURVIVAL AND GROWTH

The planting of October 1940, already described insofar as differential growth and survival between fast and slow waters are concerned, was made originally as a preliminary attempt to determine what effect, if any, the rearing of trout on various diets in the

hatchery might have on their ability to survive and grow in the wild. In brief, 1,100 of these fish had been reared on a 100-percent meat diet and the other 1,100 had been reared on a diet of meat supplemented with dry foods. The two lots were marked differently (removal of right or left maxillary bones) and planted at the same time in Crystal Creek with the hope that the annual inventory would give an estimate of the relative abundance and growth of the two lots in the following year, and thus an evaluation of the effect of the two feeding methods.

The September 1941 inventory showed a total of five of the meat-fed fish and five of those fed on meat and dry food in all 13 sections. Growth of the two lots was likewise rather similar, the average gain of the meat-fed fish being 5.32 centimeters as compared to 4.34 centimeters for the mixed-diet fish.

The number of returns of these marked fish was too small to indicate that adding dry-food supplements to the meat diet in the hatchery had any effect upon the ability of trout to survive or grow after being planted. A more extensive experiment would be desirable, however, to test more adequately the effect of these feeding practices on survival and growth.

Discussion

In those experiments where the plantings were made throughout the stream, annual inventories by means of the electrical-shocking apparatus showed a significantly greater number of hatchery fingerlings recovered from fast-water sections than from slow-water sections. There are several possible explanations: (1) that the fish preferred fast water and moved there after they had been planted; (2) that there actually was less mortality in the fast sections; or (3) that each of these conditions was responsible, in part, for the difference.

Growth in those experiments, where goodly numbers of measurements were obtained from fish in the two water types, was significantly greater for fish returned in fast-water sections than for fish retaken in slow-water sections.

In those experiments where fish were planted in screened-off areas of slow and fast water, special electrical inventories after only short periods of time showed the survival of two different plantings of fingerlings to be considerably greater in the fast-water than in the slow-water areas. Growth of those fish in the fast-water areas was also superior to growth in the slow-water areas.

The conclusion thus seems warranted that both survival and growth of the hatchery-reared fingerling brown trout planted in Crystal Creek were greater in fast water than in slow water, and for this stream at least, greatly improved results insofar as survival and growth rates are concerned would probably result by the concentration of plantings in fast water.

Of the two plantings made in the short-term experiments, the first one produced much greater growth and survival than did the second planting. The first lot differed from the second mainly in that: (1) they were planted 2 weeks before the second; (2) they were marked by the removal of fins rather than of maxillary bones; and (3) they had been reared in hatchery water of slightly different characteristics. It is possible that after being planted about 2 weeks, the first lot inhabited most of the favorable "niches" of the stream and thus competed strongly with the newcomers. It is possible also that the removal of one of the maxillary bones had a more deleterious effect on the second lot than did the removal of one of the paired fins on the first lot. Furthermore, hatchery records show that the first lot was reared in water that averaged about 5° F. closer to Crystal Creek water temperatures than the water in which the second lot was reared. The lot planted on July 14 had been reared in water averaging 60.0° F. at the Rome Hatchery. On July 14, Crystal Creek averaged 68.0° F. The lot planted August 1 had been reared in water averaging 55.0° F. and Crystal Creek on August 1 averaged 68.5° F. It would be valuable to attempt a more critical evaluation of the effect of different water supplies in the hatchery upon survival and growth of the hatchery product. Such a test could be obtained by planting under more standarized conditions, that is, planting the two lots at the same time, and having them marked in a more similar manner, and by following such plantings by periodic estimates of the relative number of the two lots surviving.

A preliminary experiment designed to evaluate the effect of various hatchery diets on survival and growth of planted fingerlings was conducted. A number of fingerlings (1,100) that had been reared on a 100-percent meat diet and 1,100 that had been reared on a meat diet supplemented with dry foods were marked differently and planted in Crystal Creek at the same time. After 11 months in the stream, no difference could be found between the survival of the two lots and their growth rates were very similar.

This experiment, although producing only a limited amount of information on the effect of feeding various diets on subsequent survival and growth, due to the fact that only a small number of returns were obtained, does however, illustrate a method for the more valid evaluation of the merits of the hatchery product, that is, by the measurement of relative survival and growth in the stream, rather than by performance in the hatcheries. Testing the effects of various hatchery methods, such as those connected with spawn-taking, feeding, diets, rearing, transportation, planting, etc., by this method would seem to offer great possibilities for increasing the quality of the hatchery product by indicating the specific variations of these methods which will result in the greatest survival and growth of hatchery fish when they are planted in streams.

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STANDARDIZATION OF METHODS OF EXPRESSING LENGTHS AND WEIGHTS OF FISH[1]

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ABSTRACT

Fishery workers in the United States and Canada are unable to think readily in terms of the metric system of weights and measurements. Even long experience does not make it possible to form a clear idea as to the actual size of fish for which lengths and weights are given in metric units, without first converting to the English system. A more general adoption of the English system of weights and measurements in fishery work is recommended. The use of English units exclusively is suggested for articles of a popular or semi-popular nature, but in more formal publications the key information, at least, should be recorded in both systems. In highly technical papers metric units alone may prove satisfactory.

Eight standard lengths, the fork length, and two total lengths of fish have been employed in fishery work. Although the standard length, under one or another of its several definitions, has enjoyed the widest use in the past, opinion is well-nigh unanimous today that we should turn to some other measurement. Agreement is lacking, however, as to which length measurement is suited best for uniform adoption. The total length is recommended here for the reason that it is the only measurement that includes all of the fish. This length is defined as the distance from the tip of the head (jaws closed) to the tip of the tail with the lobes compressed so as to give the maximum possible measurement.

Problems of standardization are by no means confined to the expression of lengths and weights. A greater uniformity in terminology and procedure would facilitate notably the exchange of information and the ready interpretation of data in almost every phase of fishery work.

The essential nature of the problems involved in the standardization of methods of stating lengths and weights perhaps can be illustrated best by the presentation of statistics on the growth of fish and specifications for some miscellaneous items of everyday existence, first in the metric system (Table 1) and later in the English system (Table 2).

The calculated standard lengths in millimeters and the calculated weights in grams at the end of 4 years of life for three stocks of yellow perch from different regions of the Great Lakes are recorded at the top of Table 1. A glance, first at the lengths, brings out immediately the existence of considerable variation. To be sure, the difference between the Saginaw Bay and Lake Erie populations is negligible. Both stocks, however, hold a large advantage over the Green Bay fish. Here, the meaningful information contributed by the data comes to an end, for if we try to gain some idea as to the actual

[1]**Presented at the Seventy-sixth Annual Meeting.**

TABLE 1.—*Statistics on the growth of fish and on other items, expressed in the metric system.*

Calculated standard lengths and weights of yellow perch at the end of 4 years		
Green Bay	166 millimeters	85 grams
Saginaw Bay	208 millimeters	165 grams
Lake Erie	209 millimeters	175 grams
Specifications for miscellaneous commonplace items		
Building lot	24.4 meters by 44.5 meters	
Oil tank	1,041 liters	
Football player	188 centimeters	95 kilograms
Beauty queen	165 centimeters	54 kilograms

size of the perch most of us find it impossible to do so without first making certain mental conversions. With the Green Bay fish, for example, we reason much as follows: "The 166 millimeters will amount to approximately 6½ inches. Then, if we add a tail we have a yellow perch between 7½ and 8 inches long." Similarly with the Saginaw Bay and Lake Erie fish we estimate that the standard lengths are roughly 8 inches and that with the addition of tails we should have yellow perch about 9½ inches long. Now for the first time is obtained some idea—sketchy, to be sure, but nonetheless gratifying—as to the true stature of the fish.

The situation is much the same with the calculated weights at the end of 4 years. It is obvious at once that the weights of the Saginaw Bay and Lake Erie perch, as well as the lengths, at this age are much the same, whereas both stocks have a notable advantage over Green Bay perch. Again, however, it is necessary to engage in certain mental gymnastics in order to arrive at a clear idea of the sizes of the fish.

Finally, specifications in the metric system for certain commonplace items of everyday existence are given at the bottom of Table 1. You are requested to deny yourself entirely the privilege of thought in terms of inches, feet, pounds, and gallons and then to make quick decisions as to whether the building lot would provide appropriate surroundings for a tiny cottage or for a 12-room house, whether the oil tank has approximately the capacity of a milk can or of a tank-truck, whether the football player is a prospect for the line or is potentially a "scatback," and whether the beauty queen. . .

Now we may turn to Table 2 which gives the same facts in the English system and with tails restored to the fish. Immediately our formerly rather nebulous and altogether unsatisfactory ideas become definite. For the yellow perch it is now seen readily—not merely estimated—that Saginaw Bay and Lake Erie fish at the end of 4 years are an inch or more above the minimum legal commercial length and at a highly desirable weight. The fish from Green Bay, on the contrary, are below legal length at the same age and would be considered by many as too light to pay for the trouble of dressing. Our commonplace, everyday items also take on meaningful proportions. The building lot will provide the average householder with at least as much lawn as he will care to mow, the tank will permit him to get

along with approximately monthly deliveries of fuel oil, the football player qualifies as a candidate for a tackle position, and even the beauty queen begins to take shape.

TABLE 2.—*Same statistics as in* Table 1, *expressed in the English system and with standard lengths replaced by total lengths.*

Calculated total lengths and weights of yellow perch at the end of 4 years		
Green Bay	7.7 inches	3.0 ounces
Saginaw Bay	9.5 inches	5.8 ounces
Lake Erie	9.6 inches	6.2 ounces
Specifications for miscellaneous commonplace items		
Building lot	80 feet by 146 feet	
Oil tank		275 gallons
Football player	6 feet, 2 inches	209 pounds
Beauty queen	5 feet, 5 inches	121 pounds

The data that have been given on the growth of fish actually bring out two problems: one concerning the length to be measured; the other bearing on the question of units to be employed. For the moment let us defer discussion of the problem as to whether it is scientifically appropriate for a fish to have a tail and ponder the question of units.

There can be little doubt that the large majority of United States and Canadian workers in fisheries find it utterly impossible to think readily in terms of the metric system. Yet we have recorded and continue to record much of our information in metric units and furthermore employ these same measurements to a large extent in our publications. By dealing in metric units we in effect place our hard-won information in code. When we determine the average length of an age group in millimeters and the average weight in grams or set up a growth curve in the metric system, we are juggling figures and not dealing with fish. We may work for long periods with such figures and never have any real idea of the size of the fish under investigation except in our more intelligent and lucid moments when we take the trouble to convert to the English system. A deplorable feature of the sitution is that our obfuscation is not alleviated by the passage of time. Many of us have handled thousands, even hundreds of thousands, of lengths and weights in metric units, but we still find them largely without meaning. Seemingly the only effective remedy lies in the adoption of English units.

Desirable as a change to the English system of weights and measurements in our fishery work appears to be, it is necessary to give consideration to arguments in favor of the metric system. Proponents of continued adherence to the metric system insist that it was scientifically conceived and is extraordinarily convenient to handle. As a counterargument, it can be stated that the inconvenience of dealing with admittedly cumbersome English units is nothing as compared to the disadvantage of using a system in terms of which we find it impossible to think. Furthermore, difficulties with the English system

can be lessened materially by the substitution of decimal fractions of inches, ounces, and pounds for the more customary halves, quarters, eighths. . .

Supporters of the metric system will argue further that in most of the non-English-speaking world metric units are employed by the general population as well as by scientists and that even in English-speaking countries much of the literature of fishery biology makes use of the metric system. In reply, we can say first that papers written in this country are intended primarily for readers in the United States and Canada; add to these the scientists to whom we send publications in Great Britain and other parts of the Empire and you will have included the bulk of the distribution of our scientific literature. It appears reasonable to employ units that are understood by the overwhelming majority of readers rather than to cling to a system that is meaningful to only a small minority. As to the argument concerning the past use of the metric system in fishery publications of this country, it can be observed only that the exercise of poor judgment in years gone by constitutes no valid reason for the perpetuation of an insufferable handicap.

Nor should we forget the general public to most of whom such esoteric statistics as standard lengths in millimeters and weights in grams must be a scant source of mental edification. The interest of the public in fish and fisheries is great; yet it can become many times greater if fishery biologists will recognize that scientific data need not be incomprehensible in order to be sound.

The recommendation is offered, therefore, that we turn to English units of weights and measurements for most of our biological work. In adopting the English system there is no necessity for us to assume a hidebound attitude. Usage always should be conditioned by circumstances. Although English units alone are indicated for articles of a popular or semi-popular nature, it probably will be desirable in more formal publications to record the key information, at least, in both the English and metric units. Furthermore, in certain highly technical publications or in special situations, as when we are dealing with extremely small fish or with small increments of growth, the metric system alone may prove satisfactory. These special concessions to expediency, however, have no bearing on the general conclusion that we should record and present our data in units in terms of which we find it possible to think.

Let us consider next the thorny question, "How long is a fish?" It is a great temptation to reply that the length of a fish is the distance from one end to the other; indeed, I should give that answer did I not fear to engender suspicion as to the soundness of my scientific outlook. There is not, however, just one length to a fish; rather, according to the latest count, there are 11 lengths that nearly every fish must have, be it the smallest minnow or a tarpon.[2] A truly

[2]If the tail is not forked, we can admit a fish with only 10 lengths.

scientific approach to the selection of a length for uniform use would require a thoughtful analysis and evaluation of the relative merits of each of the 11 lengths currently recognized. However, at the risk of total loss of reputation, I shall refrain from undertaking at this time the necessarily lengthy discussion that such a weighty problem would demand; rather, I shall mention only briefly the principal categories of lengths, and confine the more detailed remarks to certain particular lengths that have been suggested for general adoption. Most abundantly represented are the standard lengths of which there are eight. The fork length, the nature of which is self-evident from the name, appears to be a monotypic genus. Of total lengths there are two: the first, measured to the tip of the tail with that appendage in a "natural" position or in a position as nearly natural as can be attained without the willing cooperation of the fish; the second, measured to the tip of the tail with the upper and lower lobes compressed so as to give the maximum possible measurement.

Historically, the standard length appears to have been taken over from the taxonomists who by force of circumstances had little choice in the matter of the measurement to employ. There is no evidence that the borrowing of the standard length by fishery biologists was accompanied by any substantial amount of profound thinking. We did hear remarks to the effect that the standard length is *the* scientific measurement of a fish; that it reflects the true mass of the individual; that it avoids errors traceable to great variability in the relative length of the tail. . . In the main, however, the widespread use of standard lengths appears to be principally a product of imitation, habit, and mental inertia.

Standard lengths were "standard" for many years. Ultimately, however, certain congenital nonconformists appeared among fishery biologists who questioned the hitherto unquestioned superiority of the measurement. As part of this uprising, experiments were conducted that indicated the standard length to be the least accurate rather than the most accurate of length measurements (Royce, 1942; Carlander and Smith, 1945). Opinion today is well-nigh unanimous that fishery biologists should employ some length other than the standard length. Here agreement comes to an abrupt end.

The whole question of length measurements was brought rather neatly to a head, but by no means solved, in a paper by Ricker and Merriman (1945). These authors offered three major theses; with one of them it is possible to agree wholly, with another in part, with a third not at all.

They pointed out first that despite seemingly proven differences in the reliability of the several length measurements the actual extent of these differences is so small as to be of no practical significance. In other words, any of the 11 lengths that have been used by one person or another is sufficiently accurate to meet ordinary requirements. On this point there is little room for argument.

As their second thesis, Ricker and Merriman held that inasmuch as all measurements are satisfactorily accurate the selection of a length for general adoption should be based on convenience and uniformity. It can be agreed that convenience and uniformity should indeed be considered in the selection of a length measurement. On the other hand, the authors overlooked a third and far more important criterion—the length that we measure must be one in terms of which we find it possible to think naturally. On the basis of convenience and uniformity, for example, we should have to support the metric system of weights and measurements. We believe it necessary, nevertheless, to recommend English units, since we find the metric units so completely strange. The failure of Ricker and Merriman to realize the importance of naturalness in a length measurement led them into the grievous error (in their third thesis) of recommending the uniform adoption of the fork length.

The fork length is wholly unacceptable for the simple reason that it does not include all of the fish. In the face of this great shortcoming, the contentions of the authors as to the outstanding convenience of the fork length and their allegations as to its present widespread use—both points are open to question—become relatively unimportant. The real motivation behind the revolt against the standard length was, I am sure, the difficulty inherent in thinking in fractions of a fish. It is hard to see how the changing from a measurement that includes 85 percent of the animal to one that includes 92 percent gives us any real improvement. It is recommended, therefore, that in our fishery work we adopt the total length. Reference is made here to the maximum measurable length—from the tip of the head (jaws closed) to the tip of the tail with the lobes compressed—since the "natural" total length is obviously unacceptable where questions of legal minimum length are concerned.

With the above recommendation as with the one for the adoption of the English system of weights and measurements, the possible necessity of exceptions to meet special situations must be granted. Neither is a wholesale disruption of field routine proposed. On the other hand, where the immediate attainment of uniformity of procedure may prove impractical, a high degree of uniformity can be reached in the publication of results through the use of factors for conversion from one length to another. Conversion factors have been published for a number of species (see Carlander and Smith, 1945, for a most useful summary tabulation of them). It is sincerely to be hoped that many more will become available in the future.

The recommendation that total length be adopted uniformly and the specification that this length shall be the maximum possible measurement raise a question of terminology. Ricker and Merriman (1945) proposed that total length be employed only as a collective term to include the fork length, the "natural" total length, and the maximum measurable total length (to these three measurements they

assigned the names, median length, natural tip length, and extreme tip length). This proposal cannot be accepted; its adoption could lead only to confusion. In particular, the designation of the fork- or median-length measurement as a "total" length is an indefensible abuse of the scientist's prerogative of defining his own terms. The word total by common understanding and by dictionary definition connotes that no part is lacking. With the fork length a portion of the tail is excluded from the measurement; hence it cannot be "total."

As an alternative to the proposed terminology of Ricker and Merriman it is recommended that in the future the total length shall refer only to the maximum meaurable length. The fork or median length, accordingly should be designated only by one of those two terms (the former seems preferable as the more descriptive). Measurement of the "natural" total length can be abandoned.

Standard length apparently must be continued as a collective term. The resulting injury to precision in scientific articles may not be serious, however, as the suspicion cannot be avoided that the eight standard lengths differ more in definition than in dimension.

The problem of standardization of terminology, procedures, and units is by no means confined to the lengths and weights of fish. Particular mention may be made of the great diversity of terms employed in fishery publications, especially in this country, for the statement of ages of fish: winters of life; number of annuli; number of growing seasons; . . . Occasionally we see fractional ages with the value of the fraction based on the estimated number of months elapsing between the normal time of hatching and the date of capture. Roman and arabic numerals are used indiscriminately. Ordinarily the method of designating age is not ambiguous but sometimes it is. Considerable confusion can be avoided and a desirable uniformity attained if we adopt generally the method of designating ages that has long been in wide use among marine investigators and is currently standard within the Fish and Wildlife Service. In this system, fish in the first year of life are members of age-group O; those in the second belong to age-group I; . . . A useful feature of the system is that the calendar year of capture minus the age equals the calendar year of origin (that is, the year identifying the year class). In order to maintain this relationship it is necessary to follow the convention of giving each fish a birthday on January 1. This convention in turn requires that in the assessment of age we credit a virtual annulus at the edge of the scale from January 1 to the date on which the new annulus actually is completed.[3]

Other problems of standardization in fishery work can be mentioned only briefly. It would appear most desirable, nevertheless, to reach a decision as to whether morphometric data on lakes and streams in

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[3]In the southern hemisphere, of course, the maintenance of a fixed relationship among year of capture, age, and year of origin by the method proposed here runs afoul of complications, since January 1 falls in the normal growing season, not at a time of little or no growth.

fishery publications should be recorded in English or metric units; whether statistics on the production of fish or of fish food should be stated as pounds per acre or as kilograms per hectare; . . . Then too, fish-culturists are plagued by the lack of uniformity in the classification of the sizes of hatchery fish and in the methods of estimating the output of their establishments (see Rodd and Stapledon, 1942).

It is to be understood that the suggestions of the preceding pages are not in any sense to be interpreted as proposals for regimentation in fishery work or for the dictation of procedure to any individual. It is recommended rather that we, in our common interest, take steps voluntarily and after thoughtful consideration to facilitate the exchange of information and assure the issuance of more comprehensible and hence more useful publications. Nothing could be more appropriate than for this Society, the principal fishery organization on this continent, to initiate action in the matter.

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PRELIMINARY OBSERVATIONS UPON THE FERTILIZATION OF CRECY LAKE, NEW BRUNSWICK[1]

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Abstract

The fertilization of the infertile, soft waters of Crecy Lake (50 acres), New Brunswick, with ammonium phosphate and potassium chloride improved the production of plankton and bottom organisms during the summer and fall following the application of the fertilizers. The development of a heavy bloom of *Anabaena*, previously inconspicuous in the algal flora of the lake, appeared to alter environmental conditions sufficiently to have a deleterious effect upon the indigenous microcrustacea. The introduced phosphorus was rapidly removed from the water, presumably by organic growths. The greater production of plants and animals was realized without the addition of carbonates.

Introduction

The successful practice of fertilizing artificial ponds for increased fish production has directed the attention of fishery biologists to the possibilities of a similar procedure applied to natural waters such as lakes. However the control that can be exercised over the conditions in artificial ponds is largely lost in natural waters, and there is the need to demonstrate whether this practice is economically feasible in the relatively uncontrollable waters of lakes.

Limnological investigations have shown that those lakes of southern New Brunswick and southwestern Nova Scotia, which lie in formations of Precambrian and Devonian granites, quartzites, and slates, and receive the drainage from poor soils, have a low fish production. The standing crops of all species of fish in five of these lakes, as determined by poisoning, ranged from 17 to 36 pounds per acre (Smith, 1938, 1940, and 1941). Creel censuses upon eight lakes, in which there were few competitors and predators of trout, disclosed that on the average it took an angler about 2 hours to catch a trout, and the average annual yield was 0.7 pound per acre (Smith, 1946). Introduced trout contributed little to the anglers' catches unless fish of legal size were planted and these angled within a year from stocking.

The waters of these lakes are relatively infertile. The total phosphorus content varies from 0.01 to 0.02 milligram per liter. In general the pH value of the water does not exceed 7.0 and the carbonate content is low. As a result of these findings, the possibilities of enriching such lakes by fertilization is being explored, and the local problem is to determine whether the production of brook trout (*Salvelinus*

[1]One of a series of papers presented at a symposium, "Fertilization of Aquatic Areas," sponsored by the Limnological Society of America, Boston, 1946.

fontinalis), which is the principal sport fish of the area, can be increased by fertilization commensurately with the cost. An initial test is under way in Crecy Lake, Charlotte County, New Brunswick. This paper presents a descriptive account of certain conditions in the lake during the summer and fall following the fertilization. It is as yet too early to report any effects of the fertilization upon the fish production.

Survey of the Literature

Juday and Schloemer (1938) found that inorganic fertilizers (superphosphate, ammonium phosphate, muriate of potash, cyanamid, lime) sufficient to increase the phosphate content of the water five-fold and to double the amount of nitrates, had no demonstrable effect upon the plankton crop in a small Wisconsin seepage lake of 38.5 acres. On the other hand, an application of 3,000 pounds of soybean meal stimulated plankton production and was followed by an improvement in the growth of yellow perch and young smallmouth black bass. Following this lead, Wales (1946) fertilized Castle Lake (47 acres), California, with 2½ tons of soybean meal. He stated: "There is no evidence at this time to show that one application of soybean meal improved the stock of fish nor the carrying capacity sufficiently to justify the expense."

Taylor (1944) reported that the addition of a 4-8-10 (nitrogen, phosphorus, potassium) fertilizer, to give a concentration of 7.5 p.p.m. and an equal amount of crushed limestone, to Blue Lake (38 acres), Quebec, was followed in the same year by a marked increase in the weight of speckled (brook) trout. The apparent lack of data upon the normal growth rate of trout in this lake makes it difficult, however, to evaluate the role of the fertilizer.

King (1943) attributed the maintenance of a greater yield of largemouth bass and bluegills from Broadacres Lake (impounded, 21 acres), North Carolina, than from similar neighbouring lakes, to fertilization. Broadacres Lake received directly in one season 7,200 pounds of a 6-9-3 fertilizer, and, as well, the effects of an addition of 2,800 pounds of the same fertilizer and of 500 pounds of sodium nitrate to a 3-acre pond just above the lake on an inflowing tributary. It is to be noted, however, that the yield per unit of effort was not improved in Broadacres Lake during the year of fertilization over the previous season.

Gross *et al.* (1944) fertilized a small Scottish salt-water loch with sodium nitrate and superphosphate during three successive years after much of the tidal exchange of water was cut off by a dam. They found that the fertilizer was rapidly utilized by the phytoplankton; the bottom fauna improved in quantity, and the growth of young plaice and flounders was decidedly greater than in the neighbouring sea areas. The rapid utilization of the fertilizer led them to forecast that less enclosed areas of salt water could be successfully fertilized.

Limnology of Crecy Lake

The morphological characteristics of the lake may be summarized as follows:

Area	20.4 hectares (50.4 acres)
Maximum depth	3.8 meters (12.5 feet)
Mean depth	2.4 meters (7.8 feet)
Volume	486 x 10^3 cubic meters (17 x 10^6 cubic feet)
Shore development	1.18
Volume development	1.89

The lake has an outlet in which, however, the flow of water is small in late summer and may practically cease during as dry a season as 1946. There is no surface drainage by inflowing streams during the summer season.

Since the lake is shallow the waters readily mix when subjected to moderate winds and, as a result, a weak, if any, thermal stratification is found during the open-water period. Only small differences in the chemical conditions occur between the surface and bottom waters. What may be termed the mean normal conditions of the physical and chemical environment during the summer season are exemplified by the following data, largely collected in 1942:

Mid-summer temperature	21° C.
Color of water	Less than 5 (platinum-cobalt standard)
Free carbon dioxide	1 p.p.m.
Fixed carbon dioxide	3 p.p.m.
Hydrogen-ion concentration	6.7
Dissolved oxygen	92-percent saturation
Oxygen consumed	5 p.p.m. (digestion with $KMnO_4$)

Emergent aquatic vegetation is a minor feature of Crecy Lake. Stands of *Juncus militaris* occupy less than one percent of the area. Patches of *Eriocaulon septangulare* are common, however, over sandy and muddy bottoms in the littoral waters.

As far as is known, only three species of fish occur in the lake: brook trout (*Salvelinus fontinalis*), killifish (*Fundulus diaphanus*), and eels (*Anguilla bostoniensis*). The scarcity of serious competitors of trout was an important factor in the selection of Crecy Lake for a fertilization test, since obviously the presence of many undesirable fish competing for the same food supply would jeopardize a possible realization of a worthwhile improvement in the trout production.

The Fertilizer and its Application

Crecy Lake was fertilized on June 19 and 20, 1946, with one ton of ammonium phosphate (11-48-0 fertilizer) and 500 pounds of potassium chloride. The amount of fertilizer was sufficient, if adequately mixed, to give a concentratidon of 0.39 milligram of phosphorus per liter and 0.21 milligram of nitrogen per liter.

No calcium carbonate was added although its application is advocated by most workers in the fertilization of soft waters. Additional

tests are planned to obtain information upon the need for liming local lakes, when applying commercial fertilizers.

The fertilizer was broadcast over the surface of the lake in the dry form. Approximately 60 percent was applied to the littoral areas of a meter or less in depth, the remainder over the deeper water.

Investigative Procedure

For the period from June to October the bottom fauna in Crecy Lake was sampled monthly. Observations upon the chemical conditions and plankton were made fortnightly, with the exception of a few omissions in October and a more frequent sampling of the plankton, particularly when marked changes were occurring.

Similar observations were made in nearby Gibson Lake whose limnetic environment is quite comparable to that in Crecy Lake. Gibson Lake was not fertilized and served as a "control."

Phytoplankton

Counts of algae were made, with the aid of a Sedgwick-Rafter counting cell and a calibrated squared ocular micrometer, upon uncentrifuged samples of surface water. The maximum number of fields examined was 200 with the result that an estimate of the number of algae below 45 per milliliter was not obtainable.

From June 17 to July 4 the number of algae increased from less than 45 to 135 per milliliter. The diatom *Asterionella* predominated. During late July and until late August the number of algae did not exceed 45 per milliliter, but a strong bloom of *Anabaena* then developed (Fig. 1). Counts on September 9 and 26 showed 7,300 and 2,100 filaments, respectively, of this blue-green alga per milliliter. (A filament as a unit in counting contained about 10 cells.) The bloom persisted, but with less density, into November when the water of the lake still had a definite green cast. It is of interest, but difficult to evaluate, that the bloom of *Anabaena* developed after a lag period of over 2 months from fertilization, and with falling water temperatures, notwithstanding the general observation that blue-green algae as a group attain maximum flowering in summer with the highest temperatures of the season.

Blue-green algae, qualitatively and quantitatively, are minor constituents of the algal flora in Crecy and similar lakes of the region. Diatoms, green algae (desmids in variety), and more sporadically some representatives of Chrysophyceae and Dinophyceae, make up the bulk of the relatively poor phytoplankton. Water blooms have not been previously observed and no suggestion of one was noted in Gibson Lake at the time the bloom of *Anabaena* occurred in Crecy Lake. Thus the fertilization definitely stimulated greater algal growth than normal in Crecy Lake, but largely of a minor member of the indigenous flora.

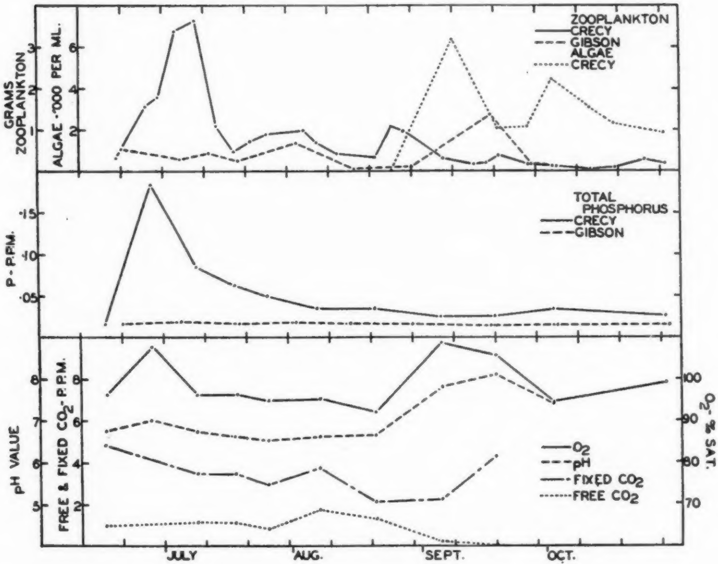

FIGURE 1.—Zooplankton and total phosphorus in Crecy and Gibson Lakes, and algae, dissolved oxygen, pH value, and free and fixed carbon dioxide in Crecy Lake.

Blooms of blue-green algae are characteristic of eutrophic lakes. Insofar as the bloom of *Anabaena* serves as an index, it illustrates a development of eutrophy, at least temporarily, by fertilization in a lake of low productive capacity.

ZOOPLANKTON

Comparative samples of zooplankton were secured from 15-minute horizontal hauls with a No. 5 plankton net towed at about one meter depth. Each sample was dried to constant weight at 58 ± 2° C. The zooplankton collected in this manner consisted almost entirely of cladocerans and copepods.

On June 20 the weight of the dried zooplankton sample was 0.32 gram. A steady increase then occurred to a maximum of 3.61 grams on July 9, followed, however, by a decline to an average level of 0.72 gram (0.32 to 1.08 grams) for the period from July 18 to August 18, and still lower to an average of 0.19 gram (0.04 to 0.30 gram) for September and October (Fig. 1).

In contrast, the quantities of zooplankton in Gibson Lake exhibited no upward trend in early July and remained smaller than in Crecy Lake until September 18 when a maximum weight of 1.63 grams was encountered (Fig. 1). The average weight for 10 samples from Gibson Lake was 0.42 gram (0.3 to 1.63 grams) as compared to an average of 0.93 gram (0.04 to 3.61 grams) for Crecy Lake during the period from June 20 to October 4.

The greater average amount of zooplankton in Crecy Lake points to a beneficial result of the fertilization, although the possibility of a difference of this order normally obtaining between the two lakes cannot be ruled out. It is considered that the action of the fertilizer was more clearly manifested by the very definite pulse in early July, since a decided increase in the zooplankton at that time was out of line with the usual seasonal trend in these lakes from a spring maximum to a comparatively low summer level.

This pulse of zooplankton was concurrent with an increase in the phytoplankton, and it is reasonable to assume that the relationship was one of cause and effect and that the algal population did not reach larger proportions because of grazing by the entomostracans (*cf.* Harvey *et al,* 1935). Pursuing this line of argument, it would have been expected that another pulse in the zooplankton would have developed with the flowering of *Anabaena.* Some hint of such an increase was given in late August when the weight of zooplankton rose to 1.08 grams, but later the algal bloom actually appeared to have an inhibitory effect upon the growth of the zooplankters (Fig. 1). There is the definite suggestion that the indigenous cladocerans and copepods were intolerant of the environmental changes which were occasioned by the bloom of *Anabaena,* such as that illustrated by an increase in the pH value from 6.6 on August 21 to 7.8 on September 6 and 8.2 on September 19.

Perhaps a comparable situation was noted by Smith and Moyle (1945) when they observed that blooms of algae in certain fertilized fish ponds were not associated with a good production of crustacea. Hardy (1936) advanced the hypothesis ("animal exclusion") that large diatom growths in the sea had an inimical effect upon zooplankters, with the result that those animals in their vertical migrations avoided concentrations of phytoplankton. Whatever these observations may have in common, the apparent incompatibility between the bloom of *Anabaena* and the growth of microcrustacea in Crecy Lake, if persistent, could seriously affect the food chain from nutrient materials to fish flesh.

Unlike its effect upon the phytoplankton, the fertilizer produced no changes in the relative abundance of the various species of entomostracans. *Diaptomus minutus* was dominant before the fertilization and throughout the summer and fall. None of the less common *Mesocylops, Epischura, Diaphanosoma, Daphnia,* or *Bosmina* approached dominance.

Bottom Fauna

The bottom fauna was sampled with an Ekman dredge which collected the material from 81 square inches of the bottom. The samples were sorted in the field through a set of three screens having 4, 13, and 20 meshes to the inch.

Eleven stations were occupied on September 25, 1945, and 10 on September 26, 1946, over the same area on the long axis of the lake at depths from 2.5 to 3.5 meters. At these depths the character of the bottom is relatively uniform as compared to the situation in the shallow water near the shores.

In 1945 the total number of bottom animals in the 11 hauls was 348 (average 32). Following the fertilization, the 10 hauls in 1946 gave 1,473 animals (average 147)—a very definite increase (Table 1). Much of the increase could be accounted for by *Hyalella* whose numbers rose from an average of 21 in 1945 to 120 per dredge haul in 1946. Improvement was noted also in the numbers of immature insects, especially caddisfly and chironomid larvae. The average numbers of all immature insects per sample were 1 and 12 in 1945 and 1946 respectively. However, mollusks (*Amnicola, Helisoma,* Sphaeriidae) remained constant in number for the two years at an average of nine per haul.

Table 1.—*Bottom fauna in Crecy Lake before and after fertilization*

Organisms	Total numbers	
	September 25, 1945 (11 stations)	September 26, 1946 (10 stations)
Planarians	....	29
Oligochaetes	....	6
Leeches	2	5
Hyalella	236	1196
Damselfly nymphs	2	5
Mayfly nymphs	2	5
Caddisfly larvae	....	34
Sialid larvae	4	4
Chironomid larvae	2	62
Beetle larvae	1	1
Bettle adult	....	1
Miscellaneous insects	....	4
Hydracarina	....	30
Amnicola	79	64
Helisoma	3	1
Sphaeriidae	17	24
Totals	348	1473

Phosphorus Content of the Water

The total phosphorus content of the water was determined by Deniges ceruleomolybdic method as outlined by Juday, Birge, and Kremmerer (1928), except that perchloric acid was employed as the oxidizing reagent (Robinson, 1941). Readings were made with an electric colorimeter, and expressed in milligrams of P per liter.

Before fertilization on June 17 and 19, 1946, the total phosphorus content averaged 0.016 milligram per liter. Sufficient fertilizer was

added on June 19 and 20 to increase the content to 0.406 milligram per liter, but values even approximating this concentration were not realized in subsequent sampling (Fig. 1). By June 27 the total phosphorus content averaged 0.183 milligram per liter and continued to fall to 0.083, 0.062, and 0.050 on July 9, 18, and 26 respectively. From August 8 to November 5 the values fluctuated between 0.025 and 0.035 milligram per liter, which, it is noted, were still above the content before fertilization in June.

Local precipitation was light from May to October in 1946, and the outflow from Crecy Lake was small. Although no actual measurements are available, it is concluded that the loss of water by drainage was insufficient during June and July to acount for the rapid drop in total phosphorus which occurred at that time. Thus the phosphorus was not lost to the economy of the lake although its fate is somewhat obscure. It is reasonable, however, to presume that much of the phosphorus was removed from the water by organic growths. A weak flowering of algae and a good development of zooplankton were correlated with the major decline in phosphorus content in late June and early July, and a reduction from 0.033 to 0.025 milligram per liter was coincident with the onset and peak of the bloom of *Anabaena*. The observations of Gross *et al.* (1944) that fertilizers were rapidly utilized in the well illuminated layers of Loch Craiglin are pertinent in this regard.

Other Chemical Factors of the Water

The dissolved-oxygen content was determined by the Winkler method and the free and fixed carbon dioxide by titration in the field with N/44 sodium carbonate and hydrochloric acid.

The greatest departures from normal conditions by the dissolved oxygen, free and fixed carbon dioxide, and hydrogen-ion concentration were caused by algal growths, particularly that of *Anabaena*. In addition to Figure 1, an appreciation of these changes is given by comparing the mean normal conditions with those that obtained on September 6 and 19, when the bloom of *Anabaena* was pronounced.

Chemical factor	*Normal*	*Sept. 6*	*Sept. 19*
Oxygen, percentage saturation	92	109	106
Free carbon dioxide, p.p.m.	1	0.2	0
Fixed carbon dioxide, p.p.m.	3	3.3	4.4
pH	6.7	7.8	8.2

In general, when algal growths decline rapidly there is also a drop in the dissolved-oxygen content, not infrequently to a level below that required for fish life. In Crecy Lake, a feature of the bloom of *Anabaena* was its persistence, so that as late as October 30 the oxygen content was near saturation. Whether a serious diminution in the oxygen supply will occur in Crecy Lake under the snow-covered ice of winter remains to be determined.

Summary of Observations on the Effects of Fertilizers

The fertilization of the infertile waters of Crecy Lake with ammonium phosphate and potassium chloride to give an additional concentration of 0.39 milligrams of phosphorus and 0.21 milligrams of nitrogen per liter resulted in an improvement in the quantity of phyto- and zooplankton and bottom fauna during the summer and fall following the application of the fertilizers.

The major growth of phytoplankton, which developed after a lag period of over 2 months but was then persistent, consisted of *Anabaena,* an alga normally inconspicuous in the lake.

The most noteworthy improvement in the quantity of cladocerans and copepods occurred soon after fertilization although it was of short duration. A depression rather than an increase in the quantity of cladocerans and copepods during the bloom of *Anabaena* suggests that the indigenous entomostracans were intolerant to the chemical changes which then took place in the water. Most radical was an increase in the pH value from 6.7 to 8.2.

The phosphorus content of the water declined rapidly after fertilization but remained at a level somewhat above the normal for the lake. The evidence at hand indicates that the drop in phosphorus content resulted principally from organic growths rather than from loss by drainage.

The fertilizers improved the productive capacity of Crecy Lake although no lime was added.

During the period of the study no depletion in the dissolved-oxygen content which could result from a sudden decline in algal populations was apparent.

Acknowledgments

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A HEAVY MORTALITY OF FISHES RESULTING FROM THE DECOMPOSITION OF ALGAE IN THE YAHARA RIVER, WISCONSIN

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ABSTRACT

A heavy loss of fish occurred in the Yahara River below Lake Kegonsa, Wisconsin, during the latter part of September and the early part of October, 1946. All species of fish in the river were affected in the mortality. The fish, crowded close to shore, were breathing at the surface and showed marked signs of distress before expiring.

Chemical analyses of the water were made in successive periods, and experiments were performed to determine the toxicity of the river water to experimental fish. Death was attributed primarily to the depletion of the oxygen supply by the decomposing algal mass consisting of almost a pure culture of *Aphanizomenon flos aquae*. Secondarily, toxic substances liberated into the water by the decomposing algae probably contributed to the death of the fish.

INTRODUCTION

A heavy loss of fish occurred in that portion of the Yahara River from the Lake Kegonsa Lock downstream to its confluence with the Rock River during the latter part of September and the early part of October 1946. Although many thousands of fish were observed, no estimate was made of the number. Carp (*Cyprinus carpio*) were the predominant fish affected. Other species observed were nothern pike (*Esox lucius*), yellow pikeperch or walleye (*Stizostedion v. vitreum*), black crappies (*Pomoxis nigro-maculatus*), bluegills (*Lepomis macrochirus*), suckers (*Catostomus commersonnii*), black bullheads (*Ameiurus m. melas*), buffalo (*Ictiobus bubalus*), hog suckers (*Hypentelium nigricans*), and an eel (*Anguilla bostoniensis*).

A series of eight representative stations was established in the 17 miles of river between the Lake Kegonsa Lock and the Rock River to study the progress of the mortality (Fig. 1).

PROGRESS OF THE MORTALITY

A huge algal mass estimated between three and four acres in area and several inches thick was moved into the bay above the Lake Kegonsa Lock by westerly winds and accompanying wave action on September 25, 1946. To prevent undesirable odors, the mass was permitted to pass through the lock by the lock tender over a 6-hour

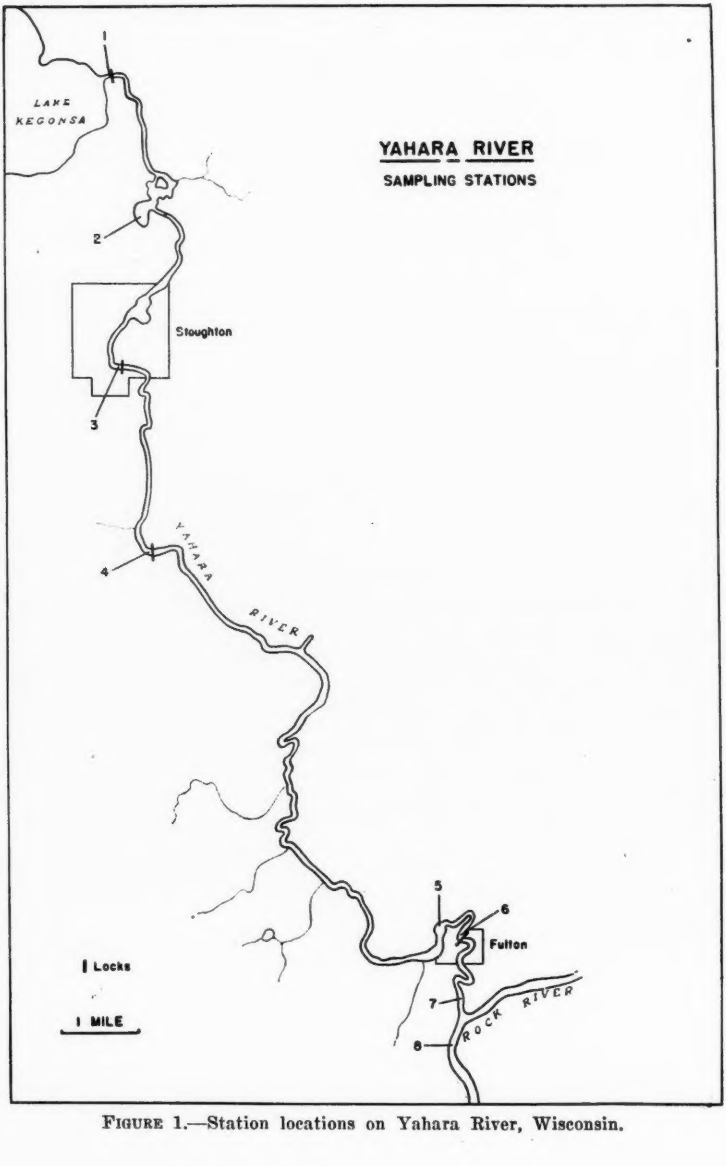

FIGURE 1.—Station locations on Yahara River, Wisconsin.

period. On September 28, 1946, it was reported that a heavy fish mortality was occurring at Stoughton, Wisconsin, 3½ miles below the lock. Upon investigation many dead and dying fish were seen at Station 2. The fish that were still alive showed signs of acute distress and were packed close to the shore, gasping at the surface. The bay at this location provided a concentration point for fish which undoubtedly were driven out of deeper water by the oxygen deficiency caused by decomposition of the algal mass (Fig. 2). Dead fish were seen floating through the lock at Stoughton, Wisconsin, located at Station 3.

On October 1, 1946, mortality was apparent at Station 4 which is 2½ miles below the previous station. Over 8,000 carp, averaging 4 pounds each, were crowded into a shallow, spring-fed stream about 500 feet long and 4 feet wide which empties into the Yahara River near this station. Above a natural fish barrier in the stream the water contained 9.6 p.p.m. of dissolved oxygen but in the lower portion there was no oxygen. The carp lived in the section of the stream where the oxygen supply remained adequate for their needs (Fig. 3).

FIGURE 2.—Dead fish in bay of Yahara River.

On October 3, 1946, the mortality had reached Stations 5 and 6, located 8 miles down the river. The conditions found here were similar to those at the previous stations.

FIGURE 3.—Carp crowding into small spring-fed stream.

TABLE 1.—*Temperature and chemical characteristics of Yahara River during the period between September 28 and October 9, 1946*

Item	Date	Stations							
		1	2	3	4	5	6	7	8
Air temperature (F.°)	Sept. 28	....	58	58	....	....	....	....	....
	Oct. 1	66	66	66	....	....	....	....	....
	do. 3	....	72	72	72	72	72	72	72
	do. 5	....	68	68	68	68	....	....	....
	do. 9	....	66	66	66	66	66	....	....
Water temperature (F.°)	Sept. 28	....	62	62	....	....	....	....	....
	Oct. 1	64	64	56	....	....	....	....	....
	do. 3	....	64	58	59	60	60	60	60
	do. 5	....	62	63	61	64	....	....	....
	do. 9	....	62	60	61	61	61	....	....
Dissolved oxygen (p.p.m.)	Sept. 28	....	0.0	0.0	....	....	....	....	....
	Oct. 1	10.2	0.4	0.8	0.8	....	....	....	....
	do. 3	....	1.5	1.8	2.4	0.2	0.1	1.0	7.8
	do. 5	....	1.8	3.7	3.8	4.5	4.3	....	....
	do. 9	....	5.1	6.4	7.8	10.0	10.4	....	....
Free carbon dioxide (p.p.m.)	Sept. 28	....	43.0	30.0	....	....	....	....	....
	Oct. 1	0.0	17.5	7.0	7.0	....	....	....	....
	do. 3	....	14.0	5.7	5.5	11.5	14.4	8.0	0.0
	do. 5	....	3.5	2.0	3.0	2.0	4.0	....	....
	do. 9	....	1.0	0.0	0.0	0.0	0.0	....	....
Hydrogen-ion concentration (pH)	Sept. 28	....	7.0	7.0	....	....	....	....	....
	Oct. 1	....	7.2	7.3	....	....	....	....	....
	do. 3	....	7.3	7.7	7.4	7.4	7.3	7.4	....
	do. 5	....	7.6	7.6	7.6	7.6	7.6	....	....
	do. 9	....	7.7	8.0	8.0	8.4	8.4	....	....
Days of maximum fish mortality	Sept. 28	....	xxxx	xxxx	....	....	....	....	....
	Oct. 1	....	....	....	xxx	....	....	....	....
	do. 3	....	....	....	....	xxxx	xxxx	....	....

Water Conditions

An examination of the river water at the time of the fish mortality showed a concentration of the blue-green alga, *Aphanizomenon flos aquae.*

The results of temperature and chemical determination are shown in Table 1. At the time of greatest mortality, the oxygen content was less than 1 p.p.m., the free carbon dioxide was high, and the pH was low. It is believed that the depletion of oxygen in the river forced the fish into the shallow bays. The greatest fish mortality seemed to take place when the decaying algal mass moved downstream. Twelve days elapsed before the water returned to a condition suitable for fish life at Stations 2 and 3. The lower stations returned to normal more rapidly because there was greater dilution of the algal mass and more wave action.

Experiments on Toxicity of River Water

An attempt was made to determine experimentally the toxicity of substances in the river water. A sample of water was taken from Station 2 during the period of greatest mortality, placed in an aquarium, and aerated. A control was set up using aerated spring water. Two yellow perch (*Perca flavescens*) and two black crappies (*Pomoxis nigro-maculatus*) were placed both in the experimental and the control aquaria. After a period of 30 hours all experimental fish had died but the control fish were still living The oxygen in the experimental tank at the end of the same period was 8.3 p.p.m.

On October 3, 1946, a similar experiment was conducted with water taken at Station 6, 14 miles down the river. Seven yellow perch, four black crappies and one common sucker (*Catostomus commersonnii*) were placed both in the experimental and the control aquaria. The yellow perch began to lose their equilibrium on October 6, 1946, and began to die on October 8, 1946. All of the fish in the experimental tank were dead on October 11, 1946, but the control fish remained alive. It is believed that the fish lived longer in this than in the earlier experiment because the algal mass was dispersed and the toxic substances diluted to such an extent that they were less harmful at the lower stations along the river.

Conclusions

It is concluded from the temperature and chemical data and from the results of experiments that the primary cause of the fish mortality was the depletion of the oxygen supply brought about by decomposition of a huge mass of *Aphanizomenon flos aquae.* Secondarily, toxic elements released by the decomposing algae probably increased the mortality.

An examination of the literature indicates that mortality produced by the decomposition of certain blue-green algae is not a new phenomenon. Fitch *et al.* (1934) who reviewed the literature on the effects of algal poisoning upon domestic animals pointed out that cattle, sheep, hogs, chickens, ducks, turkeys, and geese have been known to die soon after drinking water that contained a heavy algal growth. Rabbits and guinea pigs died suddenly after being inoculated intraperitoneally with algal suspensions extracted from live algae. Prescott (1939) stated that heavy growths of phytoplankton will deplete the oxygen supply during warm still nights and that the exhaustion of the oxygen brings about the death of both microfauna and phytoplankton. The decomposition by bacteria of this mass of organic matter quickly reduces further the oxygen content. As a result, the fish and other aquatic animals are suffocated. Prescott stated further that, "it is apparently possible for algae to bring about the death of fish through the liberation of substances toxic to them during the decay process. When highly proteinaceous blue-green algae undergo decay, sufficient quantities of hydroxylamine and other derivatives are produced to poison any fish caught in the shallow water of a bay by masses of decaying algae."

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A COMPARISON OF THE PALATABILITY OF HATCHERY-REARED AND WILD BROOK TROUT[1]

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ABSTRACT

Objective organoleptic tests scoring for aroma, flavor, texture, and moisture, were made for eight samples of wild brook trout (*Salvelinus fontinalis*) from two streams and for seven samples of hatchery-reared brook trout from two rearing stations. Samples were obtained during May, June, July, and August, were cooked separately by the same method, and identified by the judges by code number.

Average scores of six judges showed all samples acceptable but values for wild fish from both streams were significantly higher than for hatchery-reared trout. The color of the flesh and the overall appearance of the wild trout were also more attractive.

The possibility of improving the eating quality of hatchery trout through better nutrition was suggested.

INTRODUCTION

There has been considerable discussion of the relative palatability of wild trout *versus* those recently liberated from fish hatcheries. This discussion is of vital interest to those responsible for fish-management policies. The recent trend in Michigan toward planting legal-sized trout in streams shortly before and at intervals during the fishing season has resulted from studies of the survival of hatchery-reared fish stocked at various times of the year, (Hazzard and Shetter, 1939; Shetter, 1946). These studies indicate that the angler catches a greater percentage of the fish stocked when legal-sized fish are planted just prior to and during the fishing season. This trend, however, has intensified the controversy as to the comparative eating qualities of wild and hatchery-reared fish.

The present study was organized in an effort to evalute as objectively as possible the relative palatability of hatchery-reared and wild brook trout (*Salvelinus fontinalis*). It was organized and carried out jointly by the Institute for Fisheries Research, Michigan Depart-

[1]Approved by the Director of the Michigan Agricultural Experiment Station for publication as Journl Article No. 834 n.s.

ment of Conservation and Michigan Agricultural Experiment Station and Departments of Food and Nutrition and Zoology, Michigan State College.[2]

Materials and Methods

Brook trout from four sources were used in the experiment. The wild trout were obtained from Hunt Creek and the East Branch of the Au Sable River in the northern part of the lower peninsula of Michigan. No brook trout had been planted in these streams for several months or longer and the fish were regarded as wild. The hatchery-reared brook trout were obtained from the Grayling State Fish Hatchery and the Harrietta State Fish Hatchery. All fish had the entrails and gills removed at the time they were killed. They were then wrapped in waxed paper, packed in cracked ice and shipped to the Zoology Department of Michigan State College, East Lansing. Shipments were by express and were in transit only 10 to 12 hours. All lots except one arrived in good condition with ample ice. The last shipment from the Harrietta Hatchery, which was delayed, arrived without ice and was discarded. The fish were forwarded by previous arrangement in order that the judges might be available and the workers ready to prepare them.

The samples were collected at intervals of about one month throughout the period of the open fishing season. Four samples were judged during the course of the summer of 1944 as follows: May 23, June 16, July 14, and August 17.

Upon arrival in East Lansing, the fish were cleaned, prepared for cooking, and wrapped in vegetable parchment for delivery to the home economics food laboratory. The cooking was done by one person except for the trial on August 17. The preparation consisted of washing and drying the fish, then salting them lightly inside and out.

The brook trout were cooked over a low flame in heavy iron skillets containing 1½ to 2 tablespoonfuls of melted hydrogenated vegetable fat. They were cooked until brown on one side, then turned and cooked until brown on the other. The fish from each source were fried separately. Special attention was given to the selection of trout of a uniform size. The cooked fish were served to a panel of judges who had been chosen and assembled for the purpose of scoring them. Each judge was provided with score sheets on which were listed four factors: aroma, flavor, texture, and moisture. Each factor was followed by seven columns headed by adjectives describing the factor in descending order from very desirable to very undesirable. The columns were numbered one to seven, one being the lowest possible score and seven being the highest. This sheet was modified from the

[2]Fish were captured, dressed, and shipped by members of the Conservation Department. The fish were prepared for cooking and the panel of judges notified and assembled by P. I. Tack of the Zoology Section of Michigan Experiment Station. The fish were prepared, cooked and served and the scoring supervised by Miss Helen A. Baeder of the Food and Nutrition Department of the Michigan Experiment Station.

chart used by home economists for judging meats.[3] Average scores were calculated for each sample (Tables 1 and 2).

Six judges were selected as far as possible for previous experience in judging foods. An effort also was made to keep the panel balanced at half women and half men, and to keep the same judges throughout the entire experiment; this arrangement was not always possible.

The fish were identified by a code so the judges were not aware of the source of the fish they were scoring. After the judging was completed, the source of each sample was identified and the judges discussed the samples. Some of the significant comments will be mentioned in the later discussion.

The hatchery-reared brook trout were 2 years old and had been fed a diet composed of beef and pork melts and horse meat. This diet had been fed for about 1½ years. All the fish ranged from 7 to 10 inches long.

Comparison of Scores for Wild and Hatchery-reared Brook Trout

The values given in Table 1 are the mean values of the scores of six judges. They are useful in showing any possible variation of scores through the period of the experiment. An examination of individual scores shows rather close agreement within each group. Perhaps the most effective way of making comparisons is to take up one factor at a time.

Aroma.—The average score for the aroma of wild fish is the same from both sources (Table 2). The score for the hatchery-reared fish is slightly in favor of those reared at the Grayling Hatchery although the advantage over brook trout from Harrietta is not significant. In every comparison, the difference between the wild fish and the hatchery fish is significant (Table 3). It is apparent that the judges regarded all samples favorably since all values fall above four, below which would be considered unfavorable.

Flavor.—The scores for flavor showed significant differences between wild and hatchery-reared brook trout. The fish from Hunt Creek had a score considerably higher than the hatchery-reared fish and somewhat higher than the wild fish from the Au Sable River. They also rated progressively higher during the season. The fish from the Harrietta Hatchery were just acceptable while the rest were regarded as being desirable. The judges, however, did regard all wild fish superior to the hatchery-reared fish.

Texture.—The texture of the flesh may seem to be of little importance so far as quality of the fish is concerned, but some of the comments of the judges indicate that it is worthy of consideration. The judges evidently considered the texture to be better than acceptable. The differences were all significant except in the comparison between

[3]National Cooperative Meat Investigation. Committee on Cooking and Palatability Methods for Meat, United States Department of Agriculture, Washington, D. C.

TABLE 1.—*Mean scores of organoleptic tests on hatchery-reared and wild brook trout*

Source and type of fish	Date of judging	Aroma	Flavor	Texture	Moisture
Au Sable River (Wild)	May 24, 1944	5.83	5.33	5.50	5.50
	June 16, 1944	6.00	5.16	5.33	5.83
	July 14, 1944	6.33	6.50	6.00	6.16
	August 17, 1944	6.33	5.83	6.17	6.00
Average		6.13	5.71	5.75	5.88
Hunt Creek (Wild)	May 24, 1944	5.66	5.66	5.83	5.83
	June 16, 1944	5.83	5.66	5.66	6.00
	July 14, 1944	6.50	6.50	6.33	6.33
	August 17, 1944	6.50	7.00	6.83	6.67
Average		6.13	6.21	6.17	6.21
Grayling Hatchery	May 24, 1944	5.50	4.66	6.00	5.50
	June 16, 1944	5.00	4.50	4.66	5.16
	July 14, 1944	5.16	5.00	5.33	6.00
	August 17, 1944	5.17	4.67	5.83	5.67
Average		5.21	4.71	5.46	5.58
Harrietta Hatchery	May 24, 1944	5.50	4.83	5.66	4.66
	June 16, 1944	4.33	3.33	5.00	5.00
	July 14, 1944	5.00	4.00	4.83	5.33
Average		4.94	4.06	5.19	5.00

TABLE 2.—*Mean palatability scores and standard deviation of the scores for wild and hatchery-reared brook trout*

Source and type of fish	Aroma	Flavor	Texture	Moisture
Au Sable River (Wild)	6.13±.21	5.71±.26	5.75±.24	5.88±.19
Hunt Creek (Wild)	6.13±.21	6.21±.26	6.17±.21	6.21±.17
Grayling Hatchery	5.21±.22	4.71±.24	5.46±.24	5.58±.24
Harrietta Hatchery	4.94±.34	4.06±.38	5.19±.26	5.00±.26

TABLE 3.—*Values of* t *between wild and hatchery-reared brook trout*

Sources of fish	Aroma	Flavor	Texture	Moisture
Au Sable River and Grayling	[1]3.68	[1]2.86	0.85	0.97
Hunt Creek and Grayling	[1]2.88	[1]4.29	[2]2.22	[2]2.10
Au Sable and Harrietta	[1]3.72	[1]3.75	[1]5.09	[1]2.67
Hunt Creek and Harrietta	[1]3.05	[1]4.89	[1]8.91	[1]4.17

[1]The probability that this is a chance variation is less than 0.01

[2]The probability that this is a chance variation is less than 0.05

the Au Sable and Grayling fish; yet, the average scores for texture were higher for wild fish from Au Sable River than from Grayling Hatchery.

Moisture.—The scores for moisture show significant differences between the wild and hatchery-reared fish except between the fish from Au Sable River and Grayling Hatchery. Again the average scores from the Au Sable River were higher than from Grayling Hatchery.

MISCELLANEOUS COMMENTS

One noticeable feature in the cooking of the fish for these trials was the fact that the skin came off the hatchery-reared fish thus preventing browning. The wild fish retained their skin and browned nicely.

The wild fish had much more highly colored flesh than did the fish from the hatcheries. Furthermore, those from Hunt Creek were more highly colored than those from the Au Sable River. The fish from Hunt Creek had a deep-pink flesh while those from the Au Sable were only moderately pink. The hatchery-reared fish had a creamy-white flesh.

The flesh of the hatchery-reared fish had a peculiar quality which was described by some of the judges as "tacky." That is, there was a tendency for the flesh to cause the judges' teeth to stick together somewhat as they do when chewing a caramel.

Conclusion

The results of these tests suggest that there is room for improvement in the nutrition of cultured trout if the hatchery product is to equal that of natural waters.

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THE VALUE OF CERTAIN DRUGS, ESPECIALLY SULFA DRUGS, IN THE TREATMENT OF FURUNCULOSIS IN BROOK TROUT, *SALVELINUS FONTINALIS*[1]

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ABSTRACT

Furunculosis of salmonoid fishes is a dread epizootic disease caused by a general infection by *Bacterium salmonicida*.

In this experiment, treatment was tried with sulfonamides and another drug, "furacin" or "2-20-99" (new drug). The four treatments first used were: (1) sulfamerazine, (2) sulfathiazole, and (3) furacin, each administered by being mixed with the food; and (4) furacin added to the water of the troughs.

For assignment of treatments, the troughs containing fingerling brook trout, approximately 8 months old and running 30 to the pound, were grouped in four blocks of five troughs—three blocks of fingerlings with furunculosis, and one block of fingerlings of similar age and size but free from this disease. In each block, one trough received no medication. The various treatments were assigned to troughs by random selection. The block of healthy fish was to test for possible serious ill effects from any of the treatments, and was located some distance from the infected fish.

Treatments were begun August 30, 1945, and those involving sulfamerazine and sulfathiazole were continued through 25 days. The furacin treatments, less promising than the sulfonamide treatments, were replaced by sulfanilamide and sulfadiazine, each in the food, on the sixteenth day.

Furacin in the water was not beneficial but furacin in the food had some helpful effect. Results with sulfanilamide and sulfadiazine were not encouraging. Sulfathiazole seems to have been more beneficial than furacin, but decidedly less effective than sulfamerazine.

The improvement with sulfamerazine was impressive. Mortality dropped rapidly within a few days, generally was light after a week, and within 2 weeks almost completely stopped. Through 25 days, the loss was 17 percent, as compared with 50 percent among the infected lots not receiving medication.

The data indicate that 8 grams of sulfamerazine per day per 100 pounds of fish is sufficient, and that a considerably lower dose is at least beneficial.

Until further information is available, 8 grams of sulfamerazine per day per 100 pounds of fish, to be continued for at least 6 days after mortality stops, is recommended.

INTRODUCTION

Furunculosis is a destructive and dread epizootic disease of salmonoid fishes caused by a general infection by a specific bacterium. The name here accepted for this species is *Bacterium salmonicida* Lehmann and Neumann.

Emmerich and Weibel (1894) described the disease and its pathogen but failed to give the organism a name, except "Bacterien der

[1]Presented at the Seventy-sixth Annual Meeting.

Forellenseuche" ("bacteria of trout pestilence" or "bacteria of infectious disease of trout"). Lehmann and Neumann (1896) gave the name *Bacterium salmonicida.* The name *Bacillus salmonicida* has been much used (Williamson, 1928; Mackie *et al.,* 1930, 1933, 1935; Duff, 1937). However, according to Bergey's Manual (Bergey *et al.,* 1939) the genus *Bacillus* is limited to spore-forming rods. Later Marsh (1902, 1903), apparently not being familiar with this earlier work, described as *Bacterium truttae* what is believed to have been the same bacterium. On this assumption, this name is invalidated in this connection.

B. salmonicida is a short, Gram-negative, non-sporing, non-motile rod. Typically it is 2-3 microns long by 0.8 micron thick, but lengths up to 4 microns are reported (Mackie *et al.,* 1930) and coccoid or ovoid cells occur, at least in early agar cultures (Duff and Stewart, 1933).

B. salmonicida is an aerobe and a facultative anaerobe. Under aerobic conditions it develops on ordinary media at room temperatures and produces a diffusible brown pigment. It liquefies gelatin and coagulated serum, and ferments glucose and mannitol but not lactose or sucrose.

B. salmonicida is very susceptible to drying.

Plehn (1924) and Duff *et al.,* (1940) reported that this bacterium, although it dies within a few days in pure water, multiplies and survives long in dilute sewage or in water rich in organic impurities. On the other hand, according to Williamson (1928) and Mackie *et al.,* (1930, 1935), it survives only a few days in water, pure or polluted with sewage, and in nature is an obligate parasite. According to Mackie *et al.,* (1930, 1933, 1935), it is kept alive between epizootics only by very light and inactive infections of fish which serve as incubatory carriers.

Where carriers are present, epizootics may develop when water temperatures become favorable, because of crowding, after spawning, after the introduction of unexposed fish, and under influences not fully understood.

Some control has been possible, if seldom practical, by providing a great abundance of room for the fish and by providing the fish with cold water.

Duff (1942) has reported some success in immunizing trout by long continued oral administration of *B. salmonicida* vaccine.

Account of Experiment

The fish used in this experiment were brook trout, *Salvelinus fontinalis* (Mitchill), approximately 8 months old, and running 30 to the pound. For some 3 weeks, mortality had been heavy and for about 10 days very heavy. Infection with *B. salmonicida* was confirmed bacteriologically, with cultures from heart and kidney, by Dr. F. W. Hachtel, School of Medicine, University of Maryland, Baltimore.

The method used in obtaining material from the kidney for the inoculation of media is simple and rapid. A fish is killed with a sharp blow on the top of the head and then placed for a few minutes in a strong chlorine solution (not much weaker than 1 percent of available chlorine). Next the area around the place to be cut is wiped with alcohol and allowed to dry. The fish is then held, back up, in the left hand. With a sharp, sterile scalpel, the fish is cut transversely through the back, in front, or just behind, the dorsal fin. This cut is continued through, or nearly through, the kidney. If the cut does not then open and expose the kidney, it may be continued, or the portion of fish not being held may be pressed down. For small fish, the cut may well be made with scissors instead of a scalpel, as suggested by Dr. C. M. Mottley. The sample, chiefly blood, is readily taken, with sterile loop or capillary pipette, without the left hand having been shifted or the fish having been put down. Unless there are sores that might be cut, the only danger of contamination seems to be from severing the intestine, which very seldom happens.

Late in August 1945, all surviving fish were distributed among 15 parallel troughs. Ten troughs, bearing even numbers 2-20, received 16 pounds or about 480 fish each; and five troughs, bearing even numbers 22-30, 15 pounds or about 450 fish each. On August 30, five troughs at the other end of the hatchery numbered 53, 54, 56, 58, and 60, each received 15 pounds or about 450 brook trout about 8 months old and believed to be free from furunculosis.

Penicillin was considered as one of the drugs to be tried, even though there would be problems to solve in its administration with the food and even though its costliness meant that it could not be much used unless it became much cheaper. It was omitted from the experiment because none of the proper type was immediately available and its inclusion would have meant further delay.

The four treatments decided upon included the use of sulfamerazine (powder), sulfathiazole (powder),[2] and "furacin" or "2-20-99," a new drug limited by Federal Law to investigational use. Each of these was administered by being mixed with the food. In the fourth treatment, furacin, which was in tablet form, was added to the water of the troughs.

For mixing with the food, the furacin tablets were ground in a mortar. At first furacin was added to the water once a day by placing the tablets in wire boxes at the heads of the troughs; later, by leaching tablets in water, placing the disintegrated tablets above wire partitions near the heads of the troughs and adding the leachings to the water of the troughs, with the flow stopped as long as practical (about 45 minutes). Much longer treatments could have been made safely with aeration and thus have had a better chance to be effective. However, it seems improbable that such a method would be suitable for actual hatchery use.

[2] Early in the experiment, sodium sulfathiazole was used.

For assignment of treatments, the troughs were grouped in blocks of five adjacent troughs, three blocks with furunculosis, and one block of fish free from this disease. In each block, one trough or lot of fish received no medication and served as a control. The various treatments and the controls were assigned to troughs by random selection. The block of healthy fish was to test for possible serious ill effect of any of the treatments, and was located as far as possible from the infected fish.

Treatments were begun on August 30, and those involving sulfamerazine and sulfathiazole were continued through September 23 (twenty-fifth day). The furacin treatments, which seemed less promising than the sulfonamide treatments, were replaced on September 14 (sixteenth day) by sulfanilamide and sulfadiazine, each in the food.

On September 23, gill disease appeared in two troughs and soon spread. The resulting mortality largely destroyed the value of mortality data as an indication of the effectiveness, or lack of effectiveness, of furunculosis treatments and for practical purposes brought the experiment to a close. The danger from such lethal diseases is a serious one for the experimenter, and it was fortunate that this one did not appear sooner.

Except for furacin in the water, drugs were administered by being mixed with the food. To secure a satisfactory distribution through the food, the drugs were added before the dry feed was mixed, very thoroughly, with the meat. The diet was half meat and half dry feed. The fish were fed twice a day, and those being treated with drugs in their food received no food which did not contain the drug.

The assigned, or approximate, dosage rate was the same for all lots involved, except that the rate for furacin was half that for the sulfonamides. For 2 days that rate was 5 grams per day per 100 pounds of fish. For the next 3 days, it was 6.5 grams; for the next 8 days, 8 grams; and thereafter, 11.5 grams of sulfonamide per day per 100 pounds of fish.

Mortality and Survival Under the Various Treatments

The results with the various treatments (Figs. 1-7 and Table 1) are based on the removals, generally at daily intervals, of the dead fish from the various troughs. The survivals with the various treatments, including no medication (controls), are shown in Figure 7. In Figures 1-5, each point represents the mortality on a given day in the three troughs of infected fish receiving the same treatment, except that when no fish was removed on a given day (see Table 1) half of the number removed the succeeding day was assigned to the day skipped. Each of the daily losses was calculated as a percentage of the indicated number present the preceding day. The trend curves were fitted from inspection.

TABLE 1.—*Mortality of diseased (furunculosis) and sound brook trout under various treatments and without medication.*
[T— = trough number]

Date	No drugs used				Sulfamerazine in food				Sulfathiazole in food				Furacin in food (through September13)				Furacin in water (through September 13)			
	Infected fish			Sound fish	Infected fish			Sound fish	Infected fish			Sound fish	Infected fish			Sound fish	Infected fish			Sound fish
(1945)	T-8	T-12	T-28	T-58	T-2	T-14	T-30	T-54	T-4	T-20	T-26	T-53	T-10	T-18	T-22	T-60	T-6	T-16	T-24	T-56
Aug. 30	27	27	10	....	9	29	15	....	11	15	12	....	19	18	10	....	12	12	12	....
do. 31	10	19	13	....	20	24	10	....	16	17	19	....	22	14	8	....	10	9	10	....
Sept. 1	9	10	12	....	14	9	10	....	7	13	12	....	15	10	12	....	8	13	10	....
do. 2	12	12	9	....	10	10	7	....	8	12	12	....	11	13	8	....	19	10	9	....
do. 3	19	13	17	....	5	7	3	....	11	6	11	....	10	9	9	....	11	16	13	....
do. 4	30	27	17	....	9	6	6	....	19	12	7	....	12	10	8	....	20	22	15	....
do. 5	24	22	25	....	3	4	2	....	10	4	3	....	10	5	10	....	17	13	14	....
do. 6	15	16	26	....	2	....	1	....	8	2	6	....	5	5	8	....	27	19	11	....
do. 7	11	8	21	....	5	....	1	....	4	7	7	....	7	2	5	....	7	6	8	....
do. 8	6	14	12	....	1	....	1	....	1	4	2	....	10	5	....	....	23	10	9	....
do. 9	9	12	12	....	1	1	....	....	1	4	2	....	5	6	4	....	6	9	7	[3]7
do. [2]11	23	23	20	....	3	1	1	....	3	4	5	....	9	9	10	....	19	17	13	....
do. 12	6	5	14	....	....	....	....	....	1	....	3	....	5	4	....	....	8	9	6	....
do. 13	3	5	3	....	....	....	1	....	1	2	2	1	4	1	1	....	9	2	3	....
													Sulfanilamide in food				Sulfadiazine in food			
do. 14	5	5	3	....	[1]213	1	....	....	....	2	....	1	2	2	3	....	3	8	3	....
do. 15	3	6	7	....	....	....	....	....	1	....	1	....	5	5	1	....	2	4	3	....
do. 16	6	4	2	....	....	....	....	....	2	1	2	....	....	4	2	....	5	2	2	....
do. 17	3	3	2	....	1	....	....	....	....	1	....	1	2	2	1	....	2	1	2	....
do. 18	6	2	4	....	....	....	....	....	1	....	....	....	1	2	....	....	4	4	....	....
do. [2]20	3	4	2	....	....	....	....	....	1	....	2	....	2	3	3	....	4	4	5	....
do. 21	1	3	1	....	....	....	....	....	2	....	2	....	3	3	1	....	3	2	1	....
do. [2]23	2	4	2	....	....	....	....	....	....	1	2	1	5	[3]11	3	....	2	....	2	[3]1
Total mortality	233	244	234	0	83	92	58	....	108	107	112	4	164	132	107	0	221	192	158	0
Percentage	50			0	17			0	23			1	29			0	40			0

[1]Suffocated because of water supply failure; not included in total mortality

[2]Dead not removed on September 10, 19, and 22

[3]Gill disease; not included in total mortality

It will be noted that with untreated fish and those treated with furacin in water, the mortality increased for a time. The increase might mean that the epizootic had not attained its height at the start of the experiment or that the handling had aggravated the disease or reduced resistance to it.

From the table and the mortality curves, it appears that the treatment with furacin in the water was not beneficial but that furacin in the food had some helpful effect.

Results with sulfanilamide and sulfadiazine were inconclusive, but certainly there was nothing to suggest that either of these is of outstanding benefit in the treatment of furunculosis.

Sulfathiazole seems to have been definitely beneficial (Table 1 and

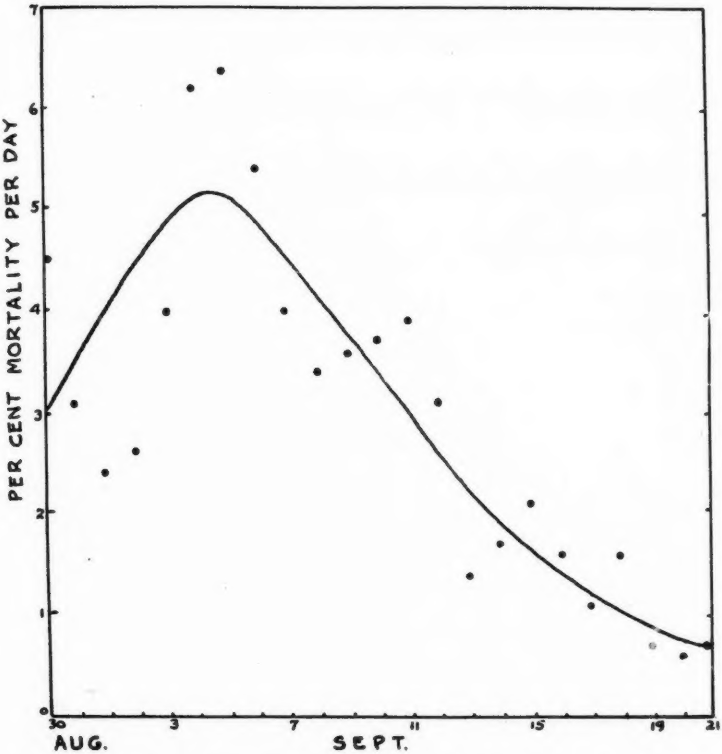

FIGURE 1.—Mortality of brook trout infected with furunculosis and receiving no medication.

Figs. 3, 6, and 7), more so than furacin in the food but decidedly less effective than sulfamerazine. Losses became light but did not stop. It is possible, of course, that heavier or more frequent doses might bring a cure.

The improvement among the fish being treated with sulfamerazine was impressive (Table 1, and Figs. 2, 6, and 7). Within a few days mortality dropped rapidly. After a week it generally was light and within 2 weeks it stopped, except for one death in each lot. This mortality does not include the heavy loss in T-2, due to almost complete stoppage of water flow (Table 1). There was no evidence of any lethal effect from the use of sulfamerazine, or of any harmful effect, except for possible growth retardation.

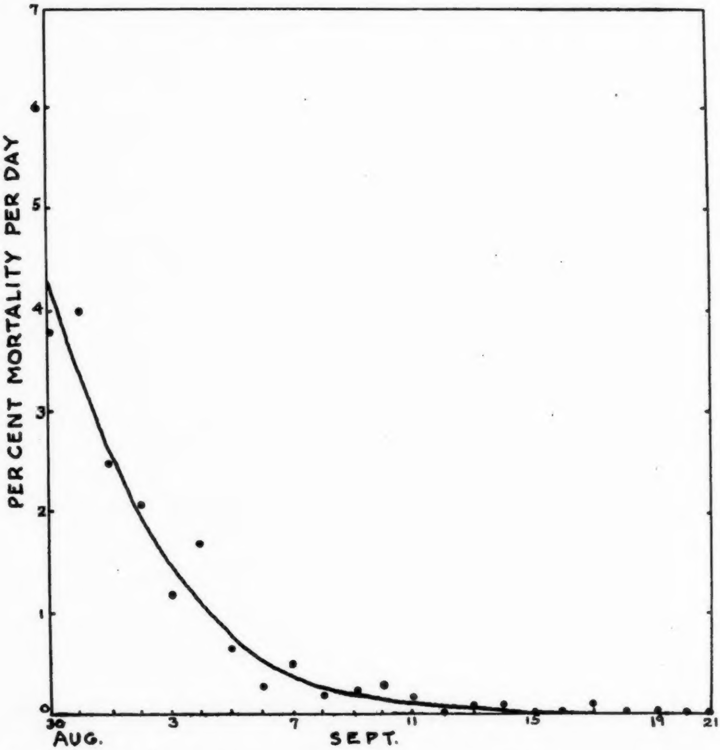

FIGURE 2.—Mortality of brook trout infected with furunculosis; sulfamerazine mixed in the food.

Discussion

The improvement with sulfamerazine was so rapid and complete as to suggest that this drug effected a cure. On this assumption, subsequent epizootics with symptoms of furunculosis, here and elsewhere, have been treated with sulfamerazine. The results, in spite of complications, are considered to have been good. Although these treatments have been without replication, controls, and other experimental safeguards, their general success is taken to afford considerable supporting evidence of the effectiveness of the drug.

In an outbreak in January 1946, more impressive than the reduction in mortality was the improvement, within a few days, in the liveliness and general appearance of health of the fish.

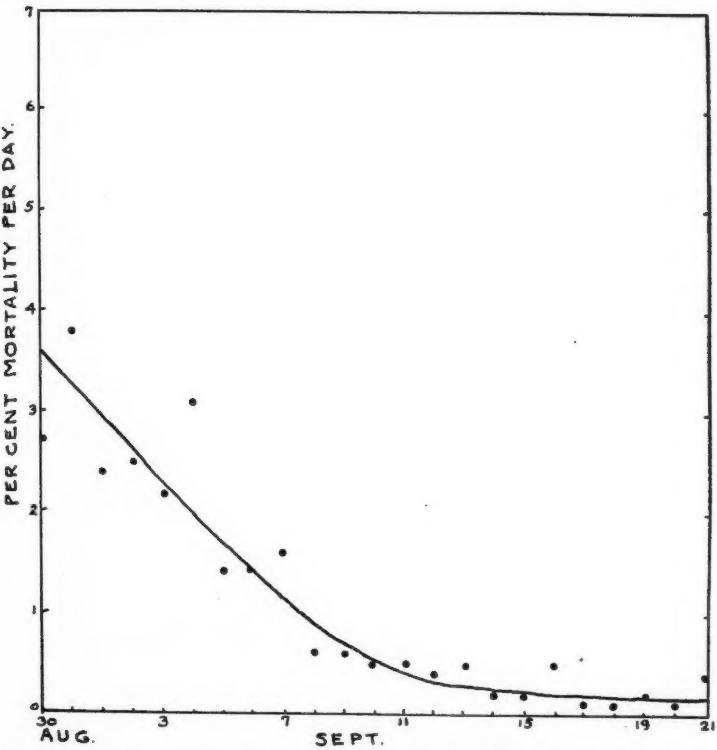

FIGURE 3.—Mortality of brook trout infected with furunculosis; sufathiazole mixed in the food.

The question of the proper dosage is important, but not easily answered. The makers state that in the treatment of acute pneumococcic, streptococcic, and meningococcic infections, the maintenance of a concentration of 10-15 milligrams per 100 milliliters of blood serum usually is sufficient, and that such concentrations in adults may be attained within 4 hours by the oral administration of 3 or 4 grams and maintained by administration of 1 gram every 8 hours or 0.5 gram every 4 hours.

Even if it is assumed that the sulfamerazine as administered will be absorbed by the fish as well as it is by humans, and that the blood concentration found best for the treatment of acute bacterial infections of humans is also the best for the treatment of *B. salmonicida*

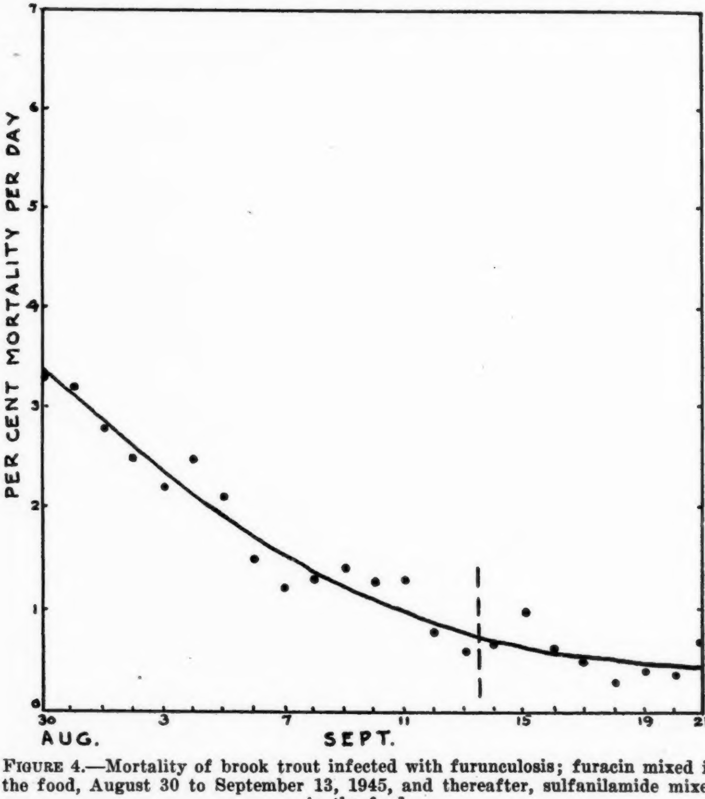

FIGURE 4.—Mortality of brook trout infected with furunculosis; furacin mixed in the food, August 30 to September 13, 1945, and thereafter, sulfanilamide mixed in the food.

infections of fish, the proper rate to use still is not easily foretold.

It is obvious that for the most expeditious cure of the disease every infected fish must receive adequate doses of the drug, and it may be assumed that some of the infected fish will take less than their share of the food. Therefore, to further adequate consumption of the drug by all fish, an increased amount of the drug should be added to the food.

It is to be supposed that, even with the utmost practical care in mixing, some portions of the food will contain comparatively little of the drug. To offset this defect, an increased amount of the drug is necessary.

Doubtless some additional amount of the drug is needed to make

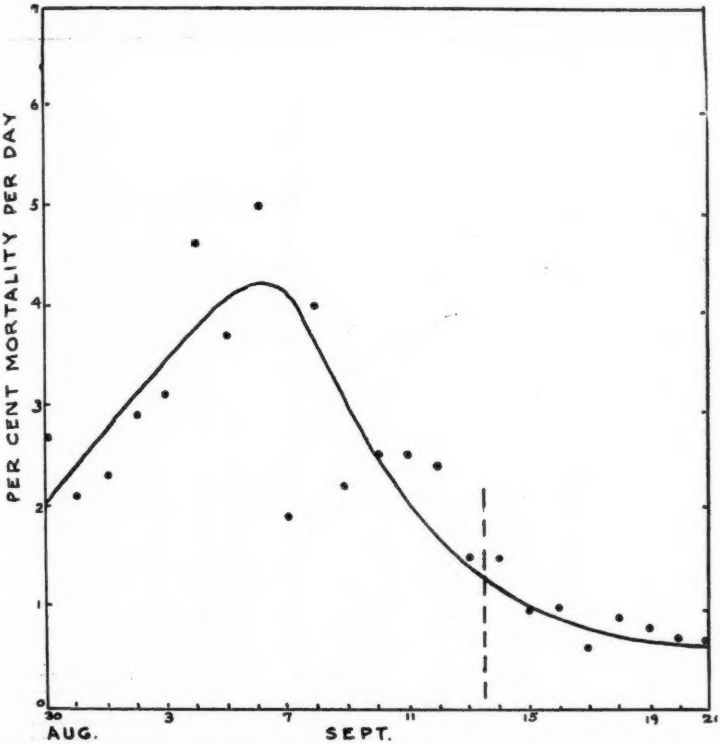

FIGURE 5.—Mortality of brook trout infected with furunculosis; furacin added to water of troughs, August 30 to September 13, 1945; thereafter, sulfadiazine mixed in the food.

up for that which is lost into the water. Because sulfamerazine is so poorly soluble in water and because trout eat what they do eat so quickly, it is believed that this loss is small, if the drug is well mixed into food of good consistency.

In most hatcheries the food and drug probably will not be given every 4 or 8 hours throughout the considerable number of days required for treatment, but either once a day or in two or three feedings during a period of 8 hours or less. Either of these methods presumably calls for a somewhat higher daily dosage than if feeding were at intervals of 4 or 8 hours.

From these various considerations, it seems that at least twice the proper individual "consumption" dose is indicated, and that the proper factor may be 3 or more.

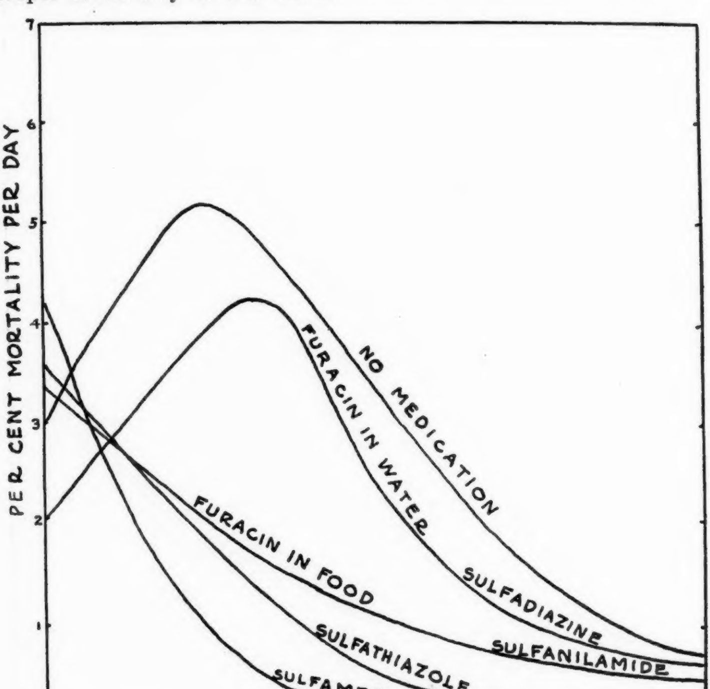

FIGURE 6.—Mortalities of brook trout infected with furunculosis; with the various treatments and in unmedicated controls.

On the assumption that the proper consumption of the drug by fish with furunculosis is the same as indicated for humans with acute pneumococcic and certain other bacterial infections, the dosage is taken to be 2 grams per day per 100 pounds of fish. On this basis, a 2X factor means 4 grams, a 3X factor means 6 grams, and a 4X factor means 8 grams of sulfamerazine per day per 100 pounds of fish (or 8.8, 13.2 and 17.6 grams per 100 kilograms).

Because it was the rate in use during most of the period in which mortality dropped from a high rate to zero, 8 grams of sulfamerazine

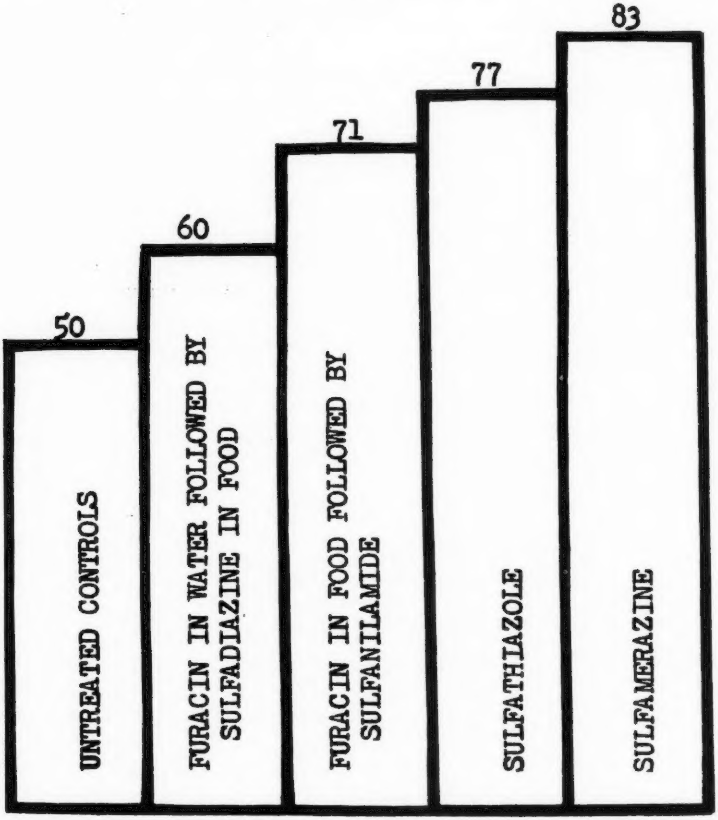

FIGURE 7.—Percentage survivals after 25 days, with the various treatments and in untreated controls.

per day per 100 pounds of fish (17.6 grams per 100 kilograms) was the rate first recommended, and used in early practical treatments. Because it is evident that the lower rates tried (5 grams and 6.5 grams per day per 100 pounds of fish) were helpful, it is hoped that a lower rate will prove sufficient. However higher as well as lower rates should be tried, and the best dosage and most effective intervals between administrations determined by careful and well designed experiments.

At present it is recommended that the drug be administered daily through 6 days after mortality stops. It is hoped thus to cure latent cases and prevent recurrence of the disease.

The effectiveness of the treatment with sulfamerazine should, of course, be checked by repeated, careful experiments. It is planned to start this experimentation soon, and at the same time to obtain evidence as to the best dose and the possible advantage of administering the drug at 8-hour intervals.

Acknowledgments

The writer wishes to thank Mr. E. W. Surber, In Charge of the Leetown Station, for giving him this assignment and for reading the manuscript. Mr. Surber, Dr. C. M. Mottley, and Dr. S. F. Snieszko have made valuable suggestions for the preparation of the final text. Authorization, from the Chief of the Division of Fishery Biology, Mr. Elmer Higgins, and Assistant Director Milton C. James, to use a large section of the hatchery, made it possible to try a number of treatments with suitable replication. Mr. Roy Furr rendered valuable assistance in carrying out the experiment. Mr. Harold Short prepared Figures 1-6.

Thanks are also due to Dr. S. F. Scheidy and Mr. H. K. Mundorf of Sharp and Dohme and to Drs. F. W. Hachtel, John C. Krantz, Jr., and H. J. Figge of the School of Medicine, University of Maryland, Baltimore. Mr. Mundorf and Dr. Scheidy suggested the trial of sulfamerazine. Dr. Figge suggested sulfathiazole, encouraged the trial of sulfamerazine and gave advice on probable safe doses. Dr. Krantz suggested the use of furacin. Dr. Hachtel not only made cultural, fermentation, and inoculation tests, and thus confirmed infection by *B. salmonicida*, but also supplied bacteriological media.

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THE FISH POPULATION OF DEEP LAKE, MICHIGAN[1]

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ABSTRACT

The fish population of Deep Lake (Oakland County, Michigan) was killed by poisoning with rotenone. It is believed that almost all of the fish 1 year old and over were recovered. An unknown number of the young-of-the-year may not have been found, although a special effort was made to recover as many of these small fish as possible. A total of 27,329 fish weighing 562.7 pounds, was recovered, or 38.0 pounds per acre. Bluegills were the most abundant species. Legal game fish made up 3.2 percent of the number and 56.1 percent of the weight of all fish recovered. Data are presented on the length, weight, and numbers of fish by age groups and year classes for the individual species. Comparison is made between the total fish population (in pounds per acre of lake surface) of Deep Lake and other natural lakes in Michigan, Wisconsin, Florida, and Nova Scotia.

INTRODUCTION

On September 12, 1941, the fish population of Deep Lake was killed by poisoning with rotenone and removed from the lake. This poisoning climaxed a 4-year study, initiated by Dr. R. W. Eschmeyer, formerly of the Institute staff, and concluded by the senior author, on the spawning habits, production, and survival of four centrarchid species in Deep Lake. The present study is an analysis of that portion of the fish population of Deep Lake that was recovered subsequent to the poisoning.

Deep Lake has been privately owned for many years. It has never been used extensively for swimming, boating, or fishing. Since 1936, the owners, a few friends and neighbors, and members of the Institute staff have been the only people who have fished on the lake. In 1937, the owners requested that the Institute make a survey of the lake and submit recommendations for its management, because they believed the lake would support trout. A preliminary survey made in 1937, indicated that the lake would be ideal for certain experiments. In 1938, permission was granted by the owners to use the lake for experimental purposes. A general biological inventory was made in 1939. Observations and experiments were begun in 1938 on many phases of the life history and reproduction of the largemouth bass, rock bass, bluegill, and pumpkinseed sunfish (Carbine, 1939). These experiments were concluded in September 1941 by the poisoning and removal of the fish population. During this period of investigation, prior to the poisoning, a total of 924 fish of all sizes were removed from the lake by Institute personnel, including the lake-inventory party.

[1]Contribution from the Michigan Institute for Fisheries Research.

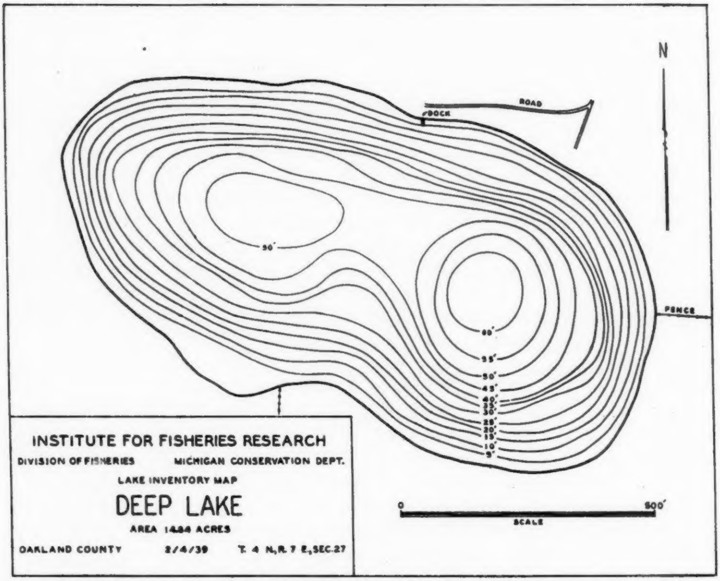
The only record of management was the introduction in May 1937 of 1,000 bluntnose minnows (*Hyborhynchus notatus*) and golden shiners (*Notemigonus crysoleucas*). Both species of minnows failed to establish themselves in Deep Lake and were never taken by seining.

Angling pressure at Deep Lake evidently has never been excessive, although prior to 1937 it is alleged to have been fished "fairly heavily." In 1938, someone was fishing on the lake nearly every day during the summer. From that year until 1941, fishing dropped off under increasingly stringent control of the use of the lake by the owners. As compared with the state as a whole, angling quality was found to be somewhat below average by Institute personnel who used the lake from 1938 to 1941. Bluegills dominated the catch, followed by the pumpkinseed and largemouth bass in that order. Yellow perch were taken only occasionally. Rock bass were taken frequently before 1939 but seldom entered the catch in 1940 and 1941.

Description of the Lake

Deep Lake is located in Section 27, T. 4 N., R. 7 E., Rose Township, Oakland County, in southeastern Michigan. The lake falls nearly perfectly into the category of pit lakes (Scott, 1921); it is surrounded by high, steep banks. Soils and terrain in the drainage area of the lake are all morainic, and the land is in cultivation, pasturage, or in farm woodlots. The high banks, from the water level to the undulating ridges above the lake, are sparsely wooded.

A biological inventory of Deep Lake was made by a survey party from the Institute for Fisheries Research on July 24, 1939. Their measurements and findings were supplemented by later examinations of the lake during the investigational work carried on there. Deep Lake has a surface area of 14.84 acres; a maximum length of 1,230 feet in a WNW-ESE direction, and a maximum width of 660 feet (Fig. 1). The lake is approximately oval and consists of two basins, an eastern with a maximum depth of 61 feet and a western with a maximum depth of 51 feet. The interdepressional area averages approximately 45 feet deep. The shoreline development is 1.12. The dropoff from the shoreline toward the center is extremely steep. That portion of the littoral zone that may be considered suitable for spawning for the warm-water species present (shore to depth of 5 feet) constitutes only 11.8 percent of the area of Deep Lake. However, the entire littoral zone, as measured by the lakeward limit of higher submerged aquatic plants, contained 37.0 percent of the lake's surface area. Higher submerged aquatic plants grow in Deep Lake up to depths of 20 feet. The northern, southern, and eastern shoal areas, varying 12 to 62 feet in width, are composed chiefly of sand interspersed with patches of gravel, rocks, roots, and vegetation. The bottom of the western shoal area, varying from 20 to 70 feet in width, is composed principally of fibrous peat, decaying vegetation, roots, and aquatic plants. There is some underlying sand and gravel in this area.



FIGUGE 1.—Map of Deep Lake, Michigan (depth contours in feet), in which the fish population was killed by poisoning with rotenone.

Patches of clay are present in some of the shoal areas, apparently deposited by the runoff from the surrounding watershed. Marl formed from decomposed *Chara* is also present in some parts of the shoal areas.

Deep Lake has neither an outlet nor a permanent inlet. One 6-inch tile, located at the southeast end of the lake, drains a nearby pasture. The lake is supplied principally by the seepage of ground water. Several small, subsurface springs are known to be present. The entire lake receives the runoff from less than 10 acres of land. Fluctuations in lake level seldom amount to more than a foot in one year.

The water in Deep Lake is relatively clear. A Secchi disk disappeared at depths of 20 to 24 feet. The transparency of Deep Lake is much greater than the average for southern Michigan lakes. At the time the survey was made (late July) the lake was both thermally and chemically stratified. A thermocline was present between 16 and 39 feet. The temperature of the water ranged from 79° F. at the surface to 42.8° F. at the bottom (61 feet). At this time oxygen was found in quantities sufficient to maintain fish life (3.0 p.p.m.) to depths of about 50 feet. Subsequent chemical analyses in late August and late

September indicated that oxygen was plentiful (3.3 p.p.m.) to a depth of 45 feet. The methyl-orange alkalinity ranged from 84 to 93 p.p.m. at the time of the survey. The pH ranged from 8.6 at the surface to 6.9 at a depth of 61 feet.

The aquatic vegetation was judged to be fairly abundant in Deep Lake, in relation to the area of suitable depth and bottom. Species found to be plentiful were the pondweed (*Potamogeton natans*) and the cattail (*Typha angustifolia*). Those considered common were the swamp loosestrife (*Decodon verticillatus*), bushy pondweed (*Najas flexilis*), needle rush (*Eleocharis acicularis*), white water lily (*Nymphaea odorata*), yellow water lily or spadderdock (*Nuphar advena*), pickerel weed (*Pontederia cordata*), the pondweeds (*Potamogeton americanus, P. amplifolius, P. angustifolius, P. gramineus, P. vaseyi,* and *P. zosteriformis*), the bulrush (*Scirpus validus*), and chara (*Chara* sp.). There is a sparse occurrence of water marigold (*Megalodonta beckii*), and coontail (*Ceratophyllum demersum*).[2]

Dense patches of bulrush were scattered over the sandy, shoal areas. Water lilies were distributed more or less evenly around the lake. An abundant patch of cattail grew at the outlet of the tile drain. The widest shoal area was covered with a rather dense mat of pondweeds, water lilies, and *Chara*. Some portions of the sandy, shoal areas were relatively free of aquatic plants. Although there was a fairly good growth of aquatic plants in Deep Lake, cover was still deemed inadequate during certain seasons of the year for all species of fish present. A few fallen trees, logs, and boulders provided a minimum of permanent shelter that could have been used during the late fall, winter, and early spring.

Methods

The destruction of the fish population of Deep Lake was accomplished by means of powdered derris root (5 percent rotenone content). Approximately 665 pounds of derris root were used, which quantity amounts to about 0.5 p.p.m. (1 part of powder to 2 million parts of water by weight). The method of applying the poison was similar to that used by Eschmeyer (1937, 1938a) and Greenbank (1940). In order to distribute the poison in the colder waters of the thermocline and the hypolimnion, large burlap bags were filled with a stiff paste of derris root, weighted and towed systemically at various depths behind a motorboat for 18 hours. The remainder of the poison was mixed with water to form a very thin suspension. This mixture was poured onto the surface of all parts of the lake from a motorboat.

The later examination of cages containing live fish placed in the lake before poisoning revealed that the poison penetrated to depths greater than 40 feet. The burlap-bag method of distributing the poison into the deeper water obviously was successful. The failure

[2]Identification of the aquatic plants was made by Mrs. Betty R. Clarke of the Botany Department, University of Michigan.

to take any fish in later netting operations indicates that all fish in Deep Lake succumbed to the poison.

A concerted effort was made to collect as many fish as possible after the poisoning at Deep Lake. Visits were made daily for 17 days following the poisoning to assure as complete a recovery as possible. It is believed that almost all of the fish 1 year old and over were picked up. No estimate can be offered as to the percentage of the young of the year that were found. A special effort was made to recover as many of these small fish as possible. However, it is believed that the recovery of the young-of-the-year bluegills, pumpkinseeds, green sunfish, and rock bass was far from complete. The problems incident to the locating of the young and the very small fish after poisoning are manifold. The roiling of the water by collectors conceals many specimens on the bottom with a fine layer of silt and detritus. Many more are hidden by beds of emergent vegetation. Furthermore in the poisoning of a lake, the smaller fish die first and Eschmeyer (1939) has shown that many are eaten by larger fish before the latter are affected by the poison. Insects, snakes, turtles, and birds also take advantage of this sudden abundance of food.

All of the fish collected at Deep Lake were sorted and identified in the field and in the laboratory by Dr. Carl L. Hubbs and Mr. Walter R. Crowe. Scale samples and length measurements were obtained from all fish over 100 millimeters long, except for the bluegills of which only a sample was taken (approximately half of the specimens above 100 millimeters). Similar data were obtained also for a large random sample of all fish less than 100 millimeters long. Aggregate weights were obtained of all of the fish recovered while individual weights were taken on only a random sample of the fish of each species. Measurements of standard and total length (to the tip of the tail with the upper and lower edge parallel) were made in millimeters and the fish were weighed to the nearest gram on a platform balance. All data on length and weight were converted to the English system and are presented here in that form.

Data on the average growth rate of certain species in Michigan waters which have been quoted in later pages have been taken from an unpublished report[3] of the Institute for Fisheries Research.

Acknowledgments

The investigation of Deep Lake was made possible through the courtesy of the owners, Messrs. James Inglis and Ben E. Young. We are indebted to Dr. R. W. Eschmeyer for the early data and for suggestions for the continuation of the investigation.

We are grateful to Dr. Carl L. Hubbs who checked identifications of fish recovered after poisoning, and who, with Mrs. Hubbs and students, helped sort and measure the samples of fish.

Most of the Institute staff aided with the poisoning and recovery of fish.

[3]Beckman, William C. Growth rate of some Michigan game fishes. Report No. 741, February 3, 1942.

Without their aid our recoveries would have been much less complete.
We are indebted to Dr. Ralph Hile for critically reviewing the manuscript.

Numbers and Weights of All Fish Recovered

The fish population was composed of 14 species at the time of poisoning. Game fish and pan fish recovered were the largemouth bass (*Huro salmoides*), bluegill (*Lepomis macrochirus*), pumpkinseed (*L. gibbosus*), green sunfish (*L. cyanellus*), hybrid sunfish in the three combinations of parent species, rock bass (*Ambloplites rupestris*), and yellow perch (*Perca flavescens*). Coarse fish recovered were yellow bullheads (*Ameiurus natalis*), mud pike (*Esox vermiculatus*), and common suckers (*Catostomus commersonnii*). Forage fish present were mudminnows (*Umbra limi*), and a single specimen of the golden shiner (*Notemigonus crysoleucas*). All species in the association are believed to have been native to the lake except the common suckers, the mudminnows, and the golden shiner. The negligible number recovered (Table 1) and the size distribution of the common suckers and golden shiners leaves little doubt that they had been introduced accidentally from fishermen's bait buckets, and the mudminnows, by occasional overflow from an adjoining permanent marsh.

A total of 27,329 fish weighing 562.7 pounds, was recovered from the lake. These recoveries amount to approximately 1,847 fish and 38.0 pounds per acre. Of the total number of fish taken, 864 or 3.2 percent of the total had attained, or were greater than, legal or a "desirable" length. (Legal length for the game and pan fishes is 6 inches except for the largemouth bass for which the legal length is 10 inches. Since there is no legal length for green sunfish and bullheads in Michigan, we have arbitrarily set 6 inches as a desirable length.) These "legal" fish were present at the rate of 58.4 fish per acre. The total weight of legal- and desirable-sized specimens was 315.4 pounds (21.2 pounds per acre) or 56.1 percent of the total poundage recovered. Data on the numbers and weight of fish of the species removed are summarized in Table 1.

The game and pan species (those accorded protection by law) in Deep Lake were the largemouth bass, rock bass, bluegill, pumpkinseed, hybrid sunfishes, and yellow perch. These five species and the hybrids accounted for 90.7 percent of the number and 87.6 percent of the weight of all fish recovered from the lake. The green sunfish has, in the past, been variously considered a pan fish or a coarse fish. Although in some southern waters it does attain a satisfactory size, it seldom exceeds 6 inches in total length in Michigan. For present purposes it is therefore considered undesirable as a pan species. The green sunfish combined with the coarse species (yellow bullhead, mud pike, and common sucker) comprised 9.3 percent of the number and 12.4 percent of the weight of all fish recovered.

TABLE 1.—*Summary of the total number and weight of each species and the number and pounds per acre of all fish recovered from Deep Lake*

Species	Number of fish	Weight (pounds)	Percentage of total number	Percentage of total weight	Number of fish per acre	Pounds per acre	Number of legal fish	Percentage of legal fish by number	Weight of legal fish (pounds)	Percentage of legal fish by weight	Number of legal fish per acre	Pounds of legal fish per acre
Bluegill	16,059	256.0	58.8	45.5	1,085.0	17.3	544	3.4	174.9	68.3	36.8	11.8
Pumpkinseed	5,935	68.9	21.7	12.2	401.0	4.7	33	0.6	7.3	10.6	2.2	0.5
Largemouth bass	785	106.0	2.9	18.8	53.0	7.2	97	12.4	79.8	75.3	6.6	5.4
Rock bass	585	22.9	2.1	4.1	40.0	1.5	46	7.9	9.9	43.2	3.1	0.7
Yellow perch	817	20.4	3.0	3.6	55.0	1.4	26	3.2	6.4	31.4	1.8	0.4
Yellow bullhead	1,082	38.4	4.0	6.8	73.0	2.6	[1]85	7.9	30.1	78.4	5.7	2.0
Green sunfish	1,090	11.0	4.0	2.0	74.0	0.7	[1]5	0.5	0.6	5.5	0.3	0.0
Mud pike	369	11.4	1.4	2.0	25.0	0.8	....	....	....	....	....	....
Common sucker	5	8.9	0.0	1.6	0.3	0.6	....	....	....	....	....	....
Mudminnow	3	0.0	0.0	0.0	0.2	[2]0.0	....	....	....	....	....	....
Golden shiner	1	0.0	0.0	0.0	0.1	[2]0.0	....	....	....	....	....	....
Bluegill × pumpkinseed	589	18.4	2.2	3.3	40.0	1.2	27	4.6	6.3	34.2	1.8	0.4
Green sunfish × pumpkinseed	7	0.3	0.0	0.0	0.5	[2]0.0	1	14.3	0.1	33.3	0.1	....
Green sunfish × bluegill	2	0.1	0.0	0.0	0.1	[2]0.0	...	....	....	....	....	....
Totals	27,329	562.7	....	....	1,847.2	38.0	864	3.2	315.4	56.1	58.4	21.2

[1]In Michigan there is no legal length on bullheads and green sunfish. Therefore, the desirable length for these species was arbitrarily set at 6 inches.
[2]Less than 0.05.

Size and Age Composition and Total Recovery of the Individual Species

No outstanding irregularities appeared in the age composition of any component species of the total population. The low number of young of the year recovered for each of the "native" species can be attributed to the difficulties of recovery (many doubtless were not found), to a low production of young in the 1941 season, and to natural death and cannibalism. In presenting these data, it is recognized that the recovered population is probably considerably less than the actual population. Young fish are, because of their size, missed more often than larger fish. Likewise young bluegills, pumpkinseeds, rock bass, and green sunfish may be missed more readily than young largemouth bass, perch, and mud pike. The spring season of 1941 in southern Michigan was apparently average and a normal production of eggs and young could have been expected in that season. The presence of strong and weak year classes in fish populations has been commonly observed. It is not known positively whether the 1941 year class was good or bad. Considerable mortality probably occurred between the time of hatching and poisoning. A period of slightly less than 2 months had elapsed since the end of spawning in Deep Lake. It is natural to expect that the number of young-of-the-year fish of all species would be greatly reduced at the time of poisoning by death from various causes including predation and cannibalism.

A discussion of the age composition and the strength of the year classes will be given in subsections for the individual species and a summary of data on year classes will be given in a later section.

Bluegill. Bluegills were the most abundant species in Deep Lake (Table 1). A total of 16,059 fish of this species weighing 256.0 pounds was recovered. These figures represent 58.8 percent of the number and 45.5 percent of the weight of the entire population. There were 544 legal-sized (36.8 per acre) bluegills (6 inches and over) which amounted to 3.4 percent of the total bluegill population recovered. The legal-sized bluegills weighed 174.9 pounds (68.3 percent of the total weight of bluegills recovered and 11.8 pounds per acre). The ratio of the number of legal- to under-sized fish was nearly 1:30. This ratio appears large in view of the fact that the population was removed from the lake only slightly less than 2 months after the last period of bluegill spawning. The relative scarcity of young probably can be attributed best to an incomplete recovery of the young of the year.

The length, weight, and number of bluegills by age groups and year classes are presented in Table 2. Of the total bluegills sampled at the time of poisoning, a sample of 673 fish comprising principally the older and larger specimens was used for age determinations. The balance were assigned to age groups according to the observed percentage age composition within the individual length intervals. (This

TABLE 2.—*The minimum, maximum, and average length and weight, and the of bluegills of each age group recovered from Deep Lake*

Age group	Year class	Number of fish aged	Estimated total number of fish in age group	Percentage of total number	Total length (inches)		Number of fish weighed[1]	Weight (ounces)	
					Range	Average		Range	Average
0	1941	73	9,872	61.5	0.6- 2.6	1.8	....	....	......
I	1940	224	5,390	33.6	1.8- 3.8	2.5	....	....	......
II	1939	36	69	0.4	3.6- 4.8	4.2	16	0.6- 1.2	0.8
III	1938	125	183	1.1	4.5- 6.7	5.4	118	0.8- 2.9	1.6
IV	1937	103	218	1.4	4.9- 8.4	6.4	104	1.1- 8.3	3.1
V	1936	20	56	0.3	7.0- 9.3	8.1	16	4.0-10.1	7.1
VI	1935	48	142	0.9	8.1- 9.9	8.9	59	6.7-13.0	9.2
VII	1934	42	123	0.8	8.6-10.0	9.4	50	7.3-14.7	11.4
VIII	1933	2	6	0.0	9.6-10.7	9.9	3	10.3-16.8	12.6
Total	....	673	16,059	....	....	....	366	....	......

[1]Individual weights were obtained from only a part of the fish from which age determinations were made

same procedure was followed for several other species.) The representations of the different age groups in the bluegill were decidedly unequal. Age-groups III, IV, VI, and VII were much stronger than age-groups II and V. The unequal representations of the different age groups are probably due to the varying degrees of success of natural reproduction in different calendar years. Hile (1941) pointed out that although the numbers of fish in the various age groups may point rather conclusively to the presence of rather rich or poor year classes in a population, they do not provide an exact measure of the true relative strength of the year classes. In estimating the relative strength of a year class it is particularly important to give consideration to the age of the fish at the time of capture. To quote from Hile (*loc. cit.*, p. 246):

> Assuming that the samples are adequate, it is true generally that a strong representation of an old age group indicates a much richer year class than does an equally large number of fish several years younger. On the other hand, a scarcity of old fish may be merely the result of natural mortality over a long period of years, whereas a scarcity of fish in a young age group is definitely suggestive of a poor year class.

For the Deep Lake bluegill population, the 123 VII-group fish (1934 year class) and the 142 VI-group fish (1935 year class) indicate a far greater original abundance for those year classes than do the numbers in groups V, IV, and III for the year classes 1936, 1937, and 1938. The 1934 and 1935 year classes had been subjected to more years of natural mortality and death from capture by anglers than had the 1936, 1937, and 1938 year classes. Likewise, the 56 V-group fish can be said to indicate a much stronger 1936 year class than the 69 II-group fish indicate for the 1939 year class. The 1939 year class (age-group II) was poorly represented and may be classed as exceptionally weak. It is believed that the 1940 year class was exceptionally strong. The 1941 year class cannot be evaluated satisfactorily because of the apparent failure to recover every fish.

The growth rate of the bluegills compares favorably with the tentative average growth rate determined for the State (Fig. 2). On the average, the bluegills were attaining legal length during their fourth season of growth. At the time of poisoning, 20.8 percent of age-group III, 71.8 percent of age-group IV, and all members of age-groups V to VIII had attained legal length. The sex ratio, based on a random sample of 365 fish (all were fish greater than 4 inches) was 42 percent males to 58 percent females.

Pumpkinseed sunfish.—The pumpkinseed ranked second in abundance and third in weight among the species in Deep Lake. A total of 5,935 pumpkinseeds weighing 68.9 pounds was removed (Table 1) or 21.7 percent of the total fish population and 12.2 percent of the total weight of all fish recovered. There were 33 legal pumpkinseeds (2.2 per acre) weighing 7.3 pounds (0.5 pounds per acre) in the lake. Legal fish comprised 0.6 percent of the number and 10.6 percent of the weight of the total number of pumpkinseeds recovered. The ratio

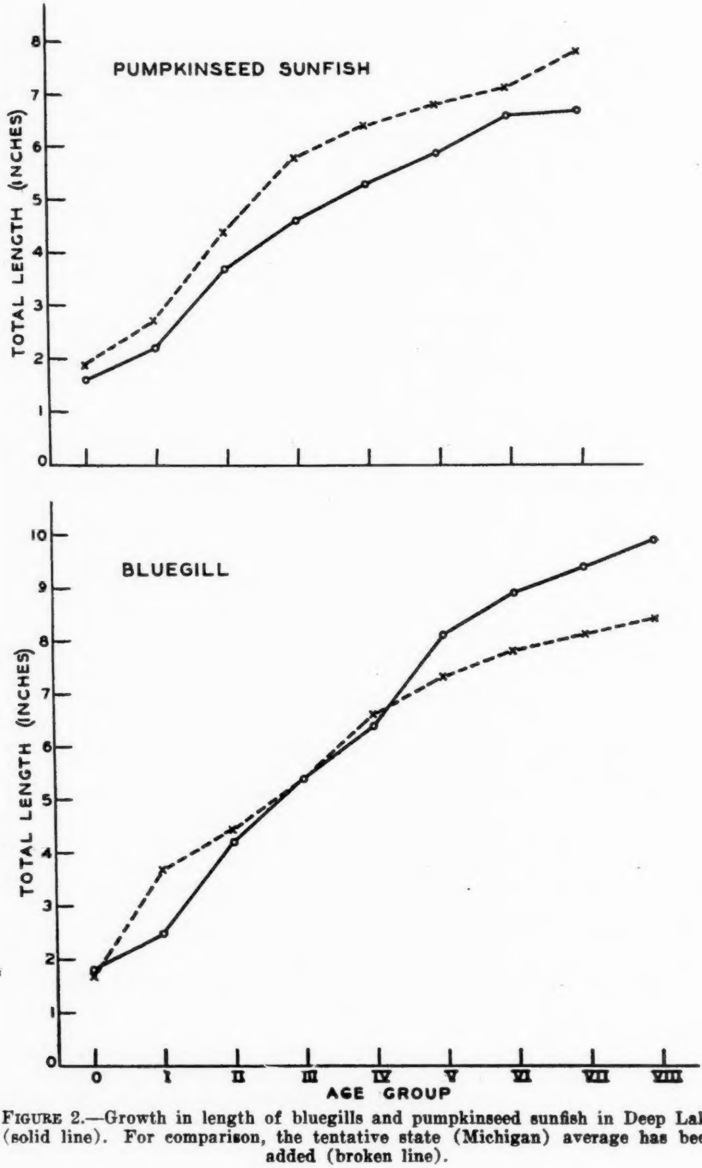


FIGURE 2.—Growth in length of bluegills and pumpkinseed sunfish in Deep Lake (solid line). For comparison, the tentative state (Michigan) average has been added (broken line).

of legal- to under-sized fish in this species was about 1:180. This ratio is much larger than that for the bluegill, but still appears disproportionate in view of the fact that there were so few legal pumpkinseeds in Deep Lake and fewer young-of-the-year fish than there were I-group fish. The growth rate of the pumpkinseeds in Deep Lake was slower than that of the bluegills and a lesser number of them appear to attain legal length (6 inches); few of them ever exceed 8 inches either in Deep Lake or in Michigan as a whole. Members of the Institute staff have noted that pumpkinseeds are much easier to catch on hook and line than bluegills. It is possible, therefore, that the few anglers that fished Deep Lake were cropping the pumpkinseeds as soon as, or shortly after they reached legal length. The effect of the slow growth rate of the pumpkinseeds cannot be ignored as a possible factor in the small number of legal-sized fish present in the lake. There is the possibility that natural mortality would reduce the numbers of the pumpkinseeds before they reached legal size. The scarcity in the number of young-of-the-year pumpkinseeds cannot be attributed entirely to poor recovery because 9,872 young-of-the-year bluegills were recovered as compared to 1,402 pumpkinseeds. This scarcity of pumpkinseeds is best attributed to a poor hatch in 1941.

The length, weight, and number of pumpkinseeds by age groups as determined from a sample of 383 fish are presented in Table 3. Of the 33 pumpkinseeds that were over 6 inches long, only 23 had scales that could be read with any degree of confidence. Two questionable specimens were discarded entirely. For this reason, the accuracy of the estimates of the number of fish in age-groups V to VII is open to some question. Age-group II (1939 year class), as among the bluegills, appears weak. Age-group O (1941 year class) likewise appears weak. Age-groups III (1938 year class) and I (1940 year class) show evidence of being exceedingly strong and indicate a much greater original abundance than age-groups O and II. The ease with which pumpkinseeds take the baited hook is probably responsible, in part at least, for the poor representation of the older and larger specimens. The natural mortality rate for these older and larger fish is also probably great.

The growth rate of the pumpkinseeds was somewhat slower than that tentatively considered average for the State (Fig. 2). Pumpkinseeds are usually expected to attain the legal length of 6 inches in southern Michigan in their fourth summer of life. The pumpkinseeds in Deep Lake were attaining legal length, on the average, late in their fifth or in their sixth growing seasons. At the time of poisoning, 8.5 percent of age-group IV, 50.0 percent of age-group V, and all of age-group VI and VII had attained legal length. The sex ratio, based on a random sample of 145 fish (all 4 inches or more in length), was 59 percent females to 41 percent males.

Bluegill × pumpkinseed hybrid sunfish.—A relatively large number of this hybrid combination was found in Deep Lake. A total of 589

TABLE 3.—*The minimum, maximum, and average length and weight, and the number of pumpkinseed sunfish of each age group recovered from Deep Lake*

Age group	Year class	Number of fish aged	Estimated total number of fish in age group	Percentage of total number	Total length (inches)		Number of fish weighed[1]	Weight (ounces)	
					Range	Average		Range	Average
0	1941	36	1,402	23.6	0.8-1.8	1.6	....	....	....
I	1940	144	4,134	69.7	1.5-3.0	2.2	74	0.1-0.3	0.2
II	1939	64	119	2.0	3.1-4.4	3.7	59	0.3-1.0	0.6
III	1938	54	142	2.4	3.8-5.6	4.6	53	0.6-1.8	1.1
IV	1937	59	102	1.7	4.3-6.7	5.3	63	0.8-3.5	1.8
V	1936	12	16	0.3	5.6-6.4	5.9	14	1.6-3.9	2.5
VI	1935	12	17	0.3	6.2-7.5	6.6	14	1.9-4.2	3.2
VII	1934	2	3	0.0	6.4-6.9	6.7	2	3.2-4.3	3.7
Total	....	383	5,935	....	....	....	279	....	....

[1]Individual weights were obtained from only a part of the fish from which age determinations were made

specimens weighing 18.4 pounds was recovered (Table 1). Bluegill × pumpkinseed hybrids made up 2.2 percent of the number and 3.3 percent of the weight of all fish recovered from the lake (rank of seven in both numbers and weight). A total of 27 hybrids (1.8 fish per acre) weighing 6.3 pounds (0.4 pounds per acre) had attained the legal size designated for the parent species. Legal fish therefore made up 4.6 percent of the total number and 34.2 percent of the total weight of the bluegill × pumpkinseed hybrids removed from the lake. The ratio of legal- to under-sized hybrids of this combination was about 1:22. This ratio may not be as unnatural as it appears since it is known that a number of factors, such as crowding on the spawning beds, which influence favorably the incidence of hybridization may be effective only in occasional years. The small number of legal-sized hybrids that were recovered may have been reduced somewhat because of the fact that hybrid sunfish were easier to catch on hook and line than were either of the parent species.

Scale samples were obtained from 423 of the 589 bluegill × pumpkinseed hybrids recovered from Deep Lake. Only 409 of these 423 specimens were useful for age determinations (Table 4). It was not

TABLE 4.—*The mimimum, maximum, and average length, the average weight and number of hybrid sunfish (bluegill x pumpkinseed) of each age group in a sample recovered from Deep Lake*

Age group	Year class	Number of fish	Total length (inches) Minimum	Average	Maximum	Average weight (ounces)
0	1941	11	1.4	1.6	1.9	....
I	1940	269	1.7	2.7	3.8	....
II	1939	56	3.1	4.1	5.3	0.9
III	1938	40	4.3	5.1	6.4	1.5
IV	1937	25	4.5	6.0	8.1	2.3
V	1936	5	6.1	7.1	8.9	4.8
VI	1935	3	8.3	8.4	8.5	8.1
Total	....	409	....	....	....	....

possible to assign age groups (see p. 207) to the 180 fish that are not considered in Table 4, because adequate records of their lengths are not available. The relative strength of year classes does not appear other than normal except for the young of the year of which very few were collected.

The growth curve of these hybrids is plotted in Figure 3 with the growth curves of the parent species for comparative purposes. These hybrids had a growth rate that was intermediate to that of the parent stock but was closer to that of their bluegill parent. On the average they were attaining legal length late in their fourth or in their fifth season of growth. It has been observed by Hubbs and Hubbs (1931, 1933) that some centrarchid hybrids have a growth rate faster than either of the parent species. This observation applied particularly to those sunfish species which in nature have comparable growth rates. In the present situation we are dealing with parent

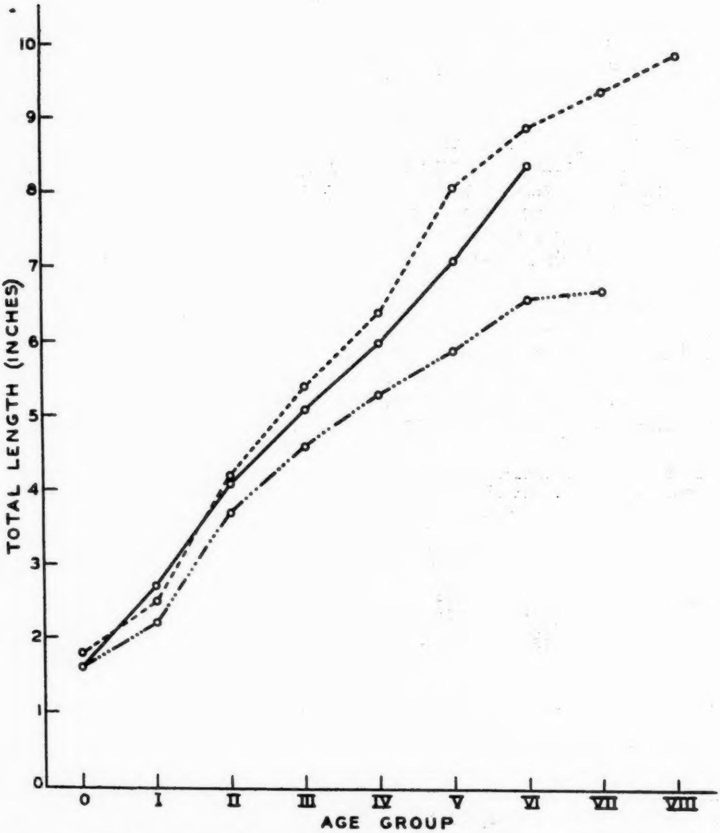


FIGURE 3.—Growth in length of the hybrid sunfish (bluegill × pumpkinseed) in Deep Lake (solid line). For comparison the growth in length of each of the parent species in Deep Lake has been added (bluegills, broken line; pumpkinseed, dots and dashes).

species having noticeably divergent growth rates, as the bluegills grew faster than the pumpkinseeds. Our data indicate a growth rate for the hybrids of the combination as being faster in each age group than the mean rate of growth of the parent species. This fact agrees in general with findings of Bailey and Lagler (1938) for the same combination of species in New York waters.

Sex data for the hybrids were not obtained at the time of collection but in all probability they were predominantly male and generally infertile (Hubbs and Hubbs, 1933).

Other centrarchid hybrids.—A total of seven green sunfish × pumpkinseed hybrids weighing 0.3 pounds was recovered. These and two bluegill × green sunfish hybrids recovered constituted such a small fraction of the total numbers and weight of fish in the lake that they will not be treated in detail. Scale samples were taken from all specimens and were used for age determinations. Six of the green sunfish × pumpkinseed hybrids were in age-group I. Their total lengths ranged from 2.0 to 2.4 inches and averaged 2.2 inches. The seventh specimen had a total length of 6.7 inches and was in its fifth summer of life (age-group IV). Of the two bluegill × green sunfish hybrids recovered, one had a total length of 2.0 inches and was in its second summer (age-group I) and the other had a total length of 4.3 inches and was in its third summer (age-group II).

Green sunfish.—Green sunfish were the third most abundant species (4.0 percent of the total number) in Deep Lake but ranked only ninth in weight (2.0 percent of the total weight). A total of 1,090 specimens weighing 11.0 pounds was recovered (Table 1). There is no minimum legal length for green sunfish in Michigan but 6 inches is arbitrarly considered to divide the desirable from the undesirable. There were no green sunfish of "desirable" length in the random sample used for age determinations. However, five specimens, 6 inches or over in total length, were recovered from the lake (0.3 desirable-sized fish per acre). The largest of these fish had a total length of 6.4 inches. The ratio of desirable to undesirable green sunfish was 1:218.

TABLE 5.—*The minimum, maximum, and average length and the number of green sunfish of each age group in a sample recovered from Deep Lake*

Age group	Year class	Number of fish in age group	Total length (inches)		
			Minimum	Average	Maximum
0	1941	10	1.2	1.5	1.7
I	1940	124	1.8	2.4	3.0
II	1939	12	3.1	3.7	4.5
III	1938	25	3.7	4.8	5.8
IV	1937	12	4.4	5.4	5.9
V	1936	1	....	5.9	....
Total	....	184	....	....	....

Scale samples were saved from a random sample of 184 specimens. Data by age groups and year classes for this sample only are summarized in Table 5. The relative strength of year classes appears normal except for the 1939 year class which, like the bluegill and pumpkinseed, shows evidences of being weak. The rate of growth (Fig. 4) was slow. On the average, the green sunfish had not attained the desirable length of 6 inches as late as the end of their sixth growing season. This growth rate, seemingly poor, is faster than that

found by Hubbs and Cooper (1935) for this species in the same general area of Michigan. These authors concluded from their study that relatively few green sunfish (in Michigan) ever attain a length of 6 inches. This and subsequent studies strongly influenced the removal of size and bag limits on this species in Michigan.

Largemouth bass.—Although the largemouth bass was only the sixth most abundant species in the lake, it ranked second in weight. The total of 785 fish recovered from the lake weighed 106.0 pounds (Table 1). Largemouth bass therefore accounted for 2.9 percent of the number and 18.8 percent of the weight of all fish removed from Deep Lake. The 97 legal-sized largemouth bass (10 inches and over) recovered weighed 79.8 pounds. The legal fish represented 12.4 percent of the total number and 75.3 percent of the total weight of the largemouth bass recovered. The ratio of legal- to under-sized largemouth bass was about 1:8. This ratio appears high and, as among the sunfishes, may be attributed to an incomplete recovery of the young of the year or to a poor hatch.

The length, weight, and number of largemouth bass by age groups and year classes are presented in Table 6. These data are based on a sample of 246 fish, including all of the fish in age-group II and older. The balance (all in age-groups O and I) were assigned to age groups according to the observed percentage age composition within the individual length intervals. The representations of the various age groups in the largemouth bass were decidedly unequal. This irregular representation is probably due to the fact that fish resulting from a particularly successful hatch prey upon the young produced in succeeding years. The 1939 year class appears weaker than earlier year classes, which situation conforms with an apparently similar phenomenon among the sunfish species. The young of the year comprising the 1941 year class might have been more abundant than the data indicate, as the recovery probably was not complete. For the largemouth bass population of Deep Lake, the 43 IV-group fish indicate that the 1937 year class was originally far more abundant than the 1938, 1939, and 1940 year classes. The 1937 year class had been subjected to more years of natural mortality and to a longer exposure to fishing than had the 1938, 1939, and 1940 year classes (all 1940 fish were below legal size). The relative strength of age-groups V to IX appears normal.

The growth rate of the largemouth bass in Deep Lake (Fig. 4) closely approximates the tentative average rate of growth for this species in Michigan waters. On the average the Deep Lake largemouth bass were attaining the legal length of 10 inches late in their third or early in their fourth growing season. At the time of poisoning, 25.0 percent of age-group II, 88.0 percent of age-group III, and all of age-groups IV to IX had attained legal length. The sex ratio, based on a random sample of 153 specimens, was 57.0 percent females to 43.0 percent males.

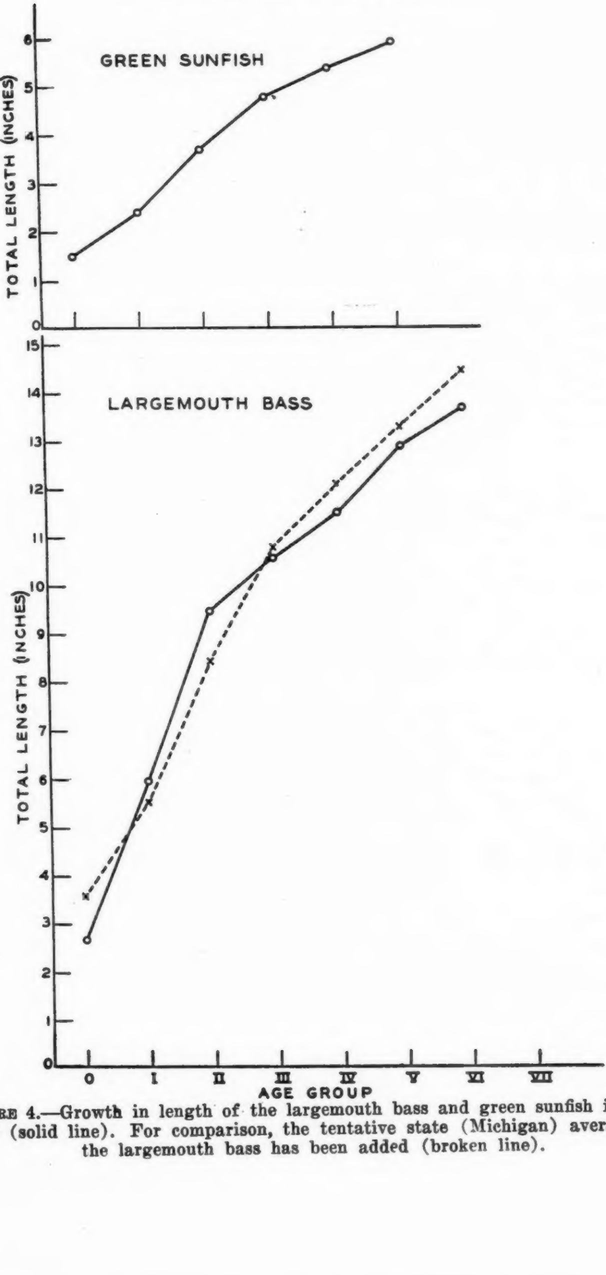


FIGURE 4.—Growth in length of the largemouth bass and green sunfish in Deep Lake (solid line). For comparison, the tentative state (Michigan) average for the largemouth bass has been added (broken line).

TABLE 6.—*The minimum, maximum, and average length and weight, and the number of largemouth bass of each age group recovered from Deep Lake*

Age group	Year class	Number of fish aged	Estimated total number of fish in age group	Percentage of total number	Total length (inches)		Number of fish weighed[1]	Weight (ounces)	
					Range	Average		Range	Average
0	1941	59	569	72.5	1.6- 4.0	2.7	569	0.1- 0.5	0.1
I	1940	75	104	13.2	4.7- 7.5	5.9	91	0.8- 2.8	1.6
II	1939	16	16	2.0	8.1-10.5	9.5	16	3.3- 9.3	6.1
III	1938	25	25	3.2	9.3-11.6	10.6	25	6.4-12.2	8.7
IV	1937	43	43	5.5	10.8-13.1	11.5	42	7.0-14.4	10.9
V	1936	18	18	2.3	11.4-13.9	12.9	18	8.5-22.0	17.8
VI	1935	7	7	0.9	12.5-15.0	13.7	7	14.5-25.0	18.2
VII	1934	1	1	0.1	15.4	15.4	1	31.5	31.5
VIII	1933	1	1	0.1	18.0	18.0	1	48.5	48.5
IX	1932	1	1	0.1	20.7	20.7	1	79.0	79.0
Total	....	246	785	....	....	....	771	....	....

[1]Individual weights were obtained from only a part of the fish from which age determinations were made

Rock bass.—This species ranked eighth in abundance (2.1 percent) and fifth in weight (4.1 percent) in the total fish population of Deep Lake. A total of 585 fish (40.0 fish per acre) weighing 22.9 pounds (1.5 pounds per acre) was recovered from the lake (Table 1). A total of 46 legal-sized (6 inches and over) rock bass (3.1 fish per acre) that weighed 9.9 pounds (0.7 pounds per acre) was recovered. Legal-sized rock bass made up 7.9 percent of the total number and 43.2 percent of the weight of this species. The ratio of legal- to under-sized rock bass was about 1:13. As in several of the species discussed previously, the ratio of legal- to under-sized fish is probably invalidated by incomplete recovery of young of the year.

The length, weight, and number of rock bass by age groups and year classes (based on a sample of 115 fish) are presented in Table 7. The relative strength of age-groups I to VII appears about normal, and all of these age groups apparently indicate a far greater original abundance than age-group O. The apparent weakness of the 1941 year class cannot be entirely due to poor recovery when we consider that a total of 4,134 pumpkinseeds and nearly 10,000 bluegills of similar size were recovered.

The rate of growth of the rock bass in Deep Lake (Fig. 5) was measurably better than that rate tentatively set up as average for this species in Michigan. This advantage of the Deep Lake fish was particularly apparent in age-groups II to V. On the average, the rock bass were attaining the legal length of 6 inches late in their fourth or in their fifth growing season. Rock bass in southeastern Michigan are usually expected to attain legal length late in their fifth or in their sixth growing season. A random sample of 69 fish (all larger than 4 inches) indicated that the sex ratio was 53.0 percent females to 47.0 percent males.

Yellow perch.—Yellow perch were fifth in abundance (3.0 percent) and sixth in weight (3.6 percent) among the entire fish population recovered in Deep Lake. A total of 817 specimens weighing 20.4 pounds was recovered (Table 1). There were 26 legal-sized (6 inches and over) yellow perch (1.8 fish per acre) which amounted to 3.2 percent of the total perch population recovered. The legal-sized perch weighed 6.4 pounds (0.4 pounds per acre) and thus made up 31.4 percent of the yellow perch population recovered. The ratio of legal- to under-sized perch was about 1:31.

A random sample of 283 yellow perch was used for purposes of age determination. Data on the age, length, and weight of the perch contained in this random sample are summarized in Table 8. It was not possible to assign the remainder of the perch population to age groups (see p. 207) because of the lack of data on their length distribution. Recovery of young-of-the-year perch may not have been complete, as was true also of all other species present in Deep Lake. The data in Table 8 suggest a numerical weakness in age-group III (1938 year class). Perch never were important as a game species

TABLE 7.—*The minimum, maximum, and average length and weight, and the number of rock bass of each age group recovered from Deep Lake*

Age group	Year class	Number of fish aged	Estimated total number of fish in age group	Percentage of total number	Total length (inches) Range	Total length (inches) Average	Number of fish weighed[1]	Weight (ounces) Range	Weight (ounces) Average
0	1941	7	73	12.5	1.3-2.0	1.6	73	....	0.1
I	1940	19	396	67.7	2.4-3.7	3.0	396	0.2-0.7	0.3
II	1939	42	56	9.6	4.2-5.9	4.8	43	0.5-2.2	1.2
III	1938	22	29	5.0	5.2-6.9	6.0	22	1.1-3.5	2.3
IV	1937	14	18	3.1	5.6-7.0	6.5	18	1.8-4.2	2.9
V	1936	7	9	1.5	6.7-8.0	7.4	9	2.7-5.6	4.4
VI	1935	2	2	0.3	8.1-8.3	8.2	2	5.6-6.2	5.9
VII	1934	2	2	0.3	7.4	7.4	2	4.9-5.6	5.3
Total	....	115	585	....	....	....	565	....	....

[1]Individual weights were obtained from only a part of the fish from which age determinations were made

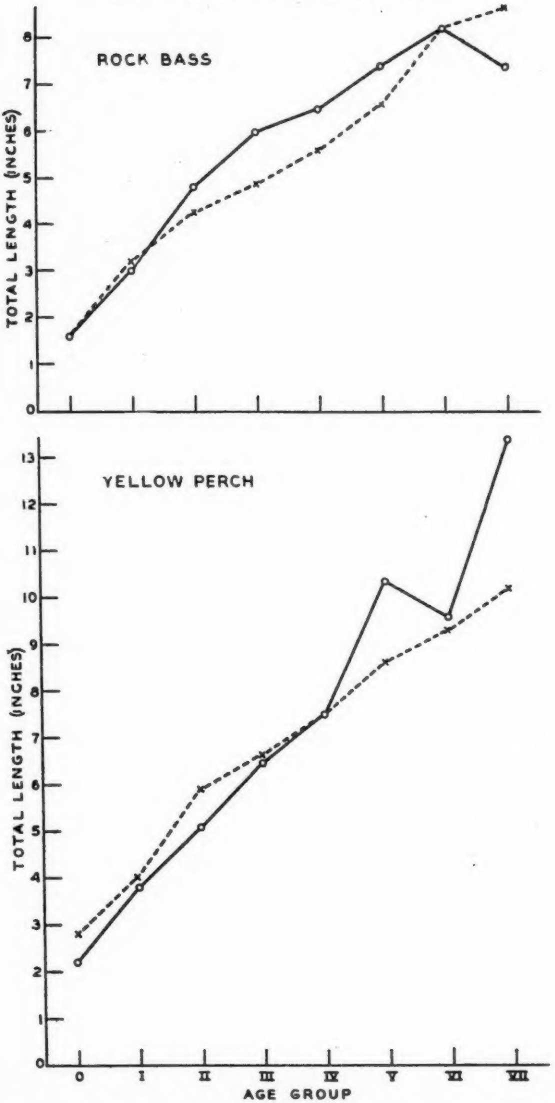


FIGURE 5.—Growth in length of the rock bass and yellow perch in Deep Lake (solid line). For comparison, the tentative state (Michigan) average has been added (broken line).

TABLE 8.—*The minimum, maximum, and average length, the average weight, and the number of yellow perch of each age group in a sample recovered from Deep Lake*

Age group	Year class	Number of fish in age group	Total length (inches)			Average weight (ounces)
			Minimum	Average	Maximum	
0	1941	53	1.6	2.2	3.1	....
I	1940	175	2.8	3.8	5.1	0.4
II	1939	30	4.2	5.1	7.2	0.9
III	1938	5	5.2	6.5	7.4	1.6
IV	1937	13	6.4	7.5	9.3	2.4
V	1936	2	10.3	10.4	10.5	6.7
VI	1935	2	9.1	9.6	10.1	....
VII	1934	1	....	13.4	....	14.5
Total	....	281	....	....	....	....

in Deep Lake and seldom entered the catch.

The growth rate of the yellow perch in Deep Lake was somewhat slower than the tentative average for the species in Michigan (Fig. 5). The perch was the only game or pan species in the lake, other than the pumpkinseeds, that had a consistently substandard rate of growth when compared with the tentative state average growth rates. Yellow perch in Michigan waters are normally expected to attain the legal length of 6 inches late in their third or early in their fourth growing season. On the average, the perch in Deep Lake required a year longer to attain this length. The sex ratio, based on a random sample of 203 specimens all of which were over 3 inches in length, was 55 percent females to 45 percent males.

Yellow bullheads.—The yellow bullhead was the more abundant of the two coarse-fish species considered native to the lake. It ranked fourth in both abundance and weight among the species present. A total of 1,082 specimens weighing 38.4 pounds was recovered. These fish represented 4.0 percent of the number and 6.8 percent of the weight of the entire population (Table 1). Lengths were obtained on all specimens and the population was arbitrarily divided into four size groups. No frequency distribution was compiled. The first group, including all specimens up to 3 inches in total length, contained 860 fish. This group included 79.4 percent of all bullheads recovered. The second group (size range, 3.1-6.0 inches, total length) contained 137 specimens; the third group (size range, 6.1-9.0 inches), included 50 specimens; the fourth group, (size range, 9.1-12.0 inches), contained 35 specimens. The 85 bullheads comprising the third and fourth size groups are considered to be of "desirable" size. They amounted to 7.9 percent of the bullheads recovered and were present in the lake at a rate of 5.7 fish per acre (2.0 pounds). Bullheads 6 inches and over in length accounted for 78.4 percent of the weight of all bullheads recovered. Anglers almost never fished for bullheads in Deep Lake.

Mud pike.—The mud pike was the less abundant of the two native coarse species in Deep Lake. A total of 369 fish of this species weighing 11.4 pounds was recovered. These figures represented 1.4

percent of the total number and 2.0 percent of the total weight of the fish population (Table 1). An examination of the scales of a random sample of fish indicated that ages could not be determined satisfactorily. A size-frequency distribution revealed only one distinct group which was assumed to be composed of the young of the year. The mode of this group was at 4.1 inches and the range was 2.5 to 5.1 inches. The group contained about 300 specimens or 81.2 percent of the population of mud pike recovered. The balance of the size distribution contained few specimens and the significance of the modes was obscure. We assume that they were probably composed of fish of age-groups II and III. The length of the larger specimens ranged up to 12.5 inches. However, only five mud pike had attained a total length greater than 10.0 inches. This species never entered the anglers' catch and may therefore be considered as a "normal" population.

Common sucker.—A total of five common suckers weighing 8.9 pounds was removed from Deep Lake. This species made up a negligible percentage of the total number and only 1.6 percent of the total weight of the fish population removed. The five specimens varied from 12.9 to 19.1 inches in total length and from 1.25 to 2.9 pounds in weight. A scale sample, saved from a 15.6-inch specimen, indicated that this fish was in its fourth season of growth (age-group III). The suckers recovered at the time of poisoning are not believed to have been native to Deep Lake. It is thought that they were introduced by fishermen who emptied their bait buckets into the lake. Suckers evidently had not become established and would probably have disappeared eventually. The reason for the failure of this species to establish itself is not apparent. Inadequate numbers, unfavorable ecological conditions, or introduction of specimens of only one sex are the possibilities suggested. Four of the suckers were recovered several days after Deep Lake was poisoned and consequently were badly decomposed. Therefore, it was impossible to determine the sex.

Golden shiner.—Only one specimen of the golden shiner was recovered. This fish was 2.5 inches long and was probably in its second season of growth (Cooper, 1936). This species, like the common suckers, is not considered native to the lake. Recovery of a single specimen of this size leaves only the conclusion that like the suckers, it was introduced from a fisherman's bait bucket.

Mudminnow.— Two specimens, 1.8 and 2.1 inches long, were recovered. They were probably in their second season of growth (Applegate, 1943). It is believed that these individuals were the result of accidental introduction but the method of their introduction is debatable. Mudminnows are not commonly used as a bait minnow in southern Michigan, which fact minimizes the possibility of their introduction by anglers. A small marsh lies just northeast of Deep Lake and is separated from the lake by a low ridge. This marsh is known to contain mudminnows. Approximately once every 4 or 5 years a very

wet spring causes this marsh to overflow slightly into the lake. This overflow provides opportunity for a periodic introduction of mud-minnows into Deep Lake. However, even though they possibly are introduced frequently, they apparently have failed to establish themselves at any time.

Comparison of the Strength of Year Classes

Although the data that have been presented in the preceding discussions point rather conclusively to the presence of relatively strong and weak year classes in the fish population of Deep Lake, they do not provide an exact measure of their relative original strength. The varying degrees of success of natural reproduction in different calendar years may be in large measure responsible for the unequal representations of the different age groups. However, such factors as incomplete recovery, annual fluctuations in angling and predation must also be considered for all species. Especially disturbing in the interpretation of the data was the distorting effect of age at capture. Despite the obvious defects in the data, however, the differences in the representation of several of the year classes are so great that a number of them can be classified by such terms as strong or weak. The following discussion on the relative abundance of the year classes was based on a careful examination of the data with allowance for the age at capture.

Certain trends in the fluctuations in the strength of various year classes doubtless have become obvious to the reader of the discussion of the age and growth of the individual species. The 1941 year class for the pumpkinseed, rock bass, yellow perch, and green sunfish seemingly was weak. For example, only 1,402 pumpkinseeds of the 1941 year class (age-group O) were recovered as compared with 4,134 fish of the 1940 year class (I-group). This scarcity of young of the year is definitely suggestive of a poor year class. The 1940 year class appeared stronger for the bluegill, pumpkinseed, rock bass, perch, and green sunfish. For example, the number of fish in the 1940 year class recovered amounted to 5,390 fish for the bluegill (9,872 for the 1941 year class), 4,134 for the pumpkinseeds (1,402 for the 1941 year class), and 396 for the rock bass (73 for the 1941 year class). The 1939 year class for the bluegill, pumpkinseed, largemouth bass, and green sunfish can be classed as weak. For example, only 69 bluegills of the 1939 year class were recovered as compared to the 183 bluegills comprising the older 1938 year class. Similar figures for other species were: pumpkinseed, 119 fish in the 1939 year class, and 142 for 1938; for the largemouth bass, 16 fish as compared with 25; and green sunfish, 12 compared with 25. From the data presented above it is apparent that in certain years survival for most species was either exceptionally good or exceptionally poor. Also, that when a good hatch of several species was evidenced by a strong year class (such as 1940) a weak year class apparently developed the following year

(1941). This phenomenon in all probability is due only to predation The fluctuation in abundance of various year classes suggests cycles which are more prominent in younger year classes than among older fish.

The strength of year classes over the period 1938 to 1934 is exceedingly difficult to evaluate, but some year classes of certain species are obviously strong or weak. The weak year classes were as follows: 1938—largemouth bass and perch; 1936—bluegill. The strong year classes were: 1938—pumpkinseed and green sunfish; 1937—largemouth bass and perch; 1935—bluegill; 1934—bluegill. The fact that the 1938 year class for the largemouth bass and perch was rather weak, whereas the 1937 year class for the same species appeared strong provides additional evidence of cyclic trends in the strength of year classes.

Fish Production in Deep Lake

It is difficult to state whether the standing crop of fish in Deep Lake (38.0 pounds per acre) represents good or poor production. A comparison with a number of fish-population studies made on natural lakes in Michigan, Wisconsin, Florida, and Nova Scotia (Table 9) leaves little doubt that regional location (regional is used here in a broad sense and is not to be confused with small regions) is a poor index of lake productivity. O'Donnell (1943) reported standing crops of 92 to 186 pounds per acre in three lakes in northern Wisconsin. Brown and Ball (1943) determined that Third Sister Lake in the southern part of the Lower Peninsula of Michigan had a population of 86.6 pounds per acre. Again in Michigan, four lakes in the upper part of the Lower Peninsula (Eschmeyer, 1938b) yielded recoveries of 21 to 194 pounds per acre. Smith (1938) found the stocks of fish in three Nova Scotian lakes to amount to 17.0, 19.9, and 36.0 pounds

Table 9.—*The total fish population (in pounds per acre of lake surface) of natural lakes in Michigan, Wisconsin, Florida, and Nova Scotia*

Name of lake	Locality (state or province)	Area (acres)	Total population (pounds per acre)	Reference
Burke	Michigan	1.8	60.1	........[1]
Third Sister	do.	10.0	86.6	Brown and Ball (1943)
Walsh	do.	10.2	92.4	........[1]
Ford	do.	10.7	48.6	Eschmeyer (1938b)
Clear	do.	11.3	194.5	do.
Howe	do.	13.4	38.0	do.
Standard	do.	16.0	21.0	do.
East Twin	Wisconsin	13.0	186.0	O'Donnell (1943)
West Twin	do.	13.5	92.0	do.
Long	do.	27.1	135.0	do.
Little Steep Pond	Florida	2.1	105.2	Meehean (1942)
Big Prairie Pond	do.	4.0	60.8	do.
First Pond	do.	7.0	110.4	do.
Buck Pond	do.	18.0	32.7	do.
Clearwater	do.	24.0	22.2	do.
Tedford	Nova Scotia	5.2	36.0	Smith (1938)
Jesse	do.	45.0	19.9	do.
Boar's Back	do.	55.8	17.0	do.

[1]Unpublished data in files of the Institute for Fisheries Research

per acre. Five natural lakes in Florida (Meehean, 1942) contained from 22 to 110 pounds per acre.

Data, as yet unpublished, in the files of the Institute for Fisheries Research on the populations and production of Walsh and Burke Lakes in the southern part of the Lower Peninsula were examined. These two lakes combined with Third Sister Lake (Brown and Ball, 1943) had an average standing crop of 79.7 pounds per acre (range, 60.1 to 92.4 pounds). Average production of legal game fish in the three lakes was 57.2 pounds per acre (range, 22.9 to 78.9 pounds). Deep Lake, although situated in the same general latitude in the Lower Peninsula as the aforementioned three lakes, had a population of less than half as many pounds of fish per acre as the average for Walsh, Burke, and Third Sister Lakes.

With the exception of one lake (Clear), Deep Lake had a population in pounds per acre comparable with those examined by Eschmeyer in the northern half of the Lower Peninsula. The population was also similar to that found by Smith in the Nova Scotian lakes. Pounds of fish per acre were considerably lower than the figures reported by O'Donnell for three lakes in northern Wisconsin.

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AN APPARATUS FOR OXYGENATING TEST SOLUTIONS IN WHICH FISH ARE USED AS TEST ANIMALS FOR EVALUATING TOXICITY

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ABSTRACT

An apparatus is described which may be used to supply adequate concentrations of dissolved oxygen to fish test jars without "blowing out" volatile toxic components. The apparatus provides for an interface contact between pure oxygen and the sample for gentle agitation to facilitate adequate oxygen absorption and diffusion. Experimental data prove that the use of the apparatus has no apparent detrimental effect on the test animals and prove that the rate of loss of a volatile toxic component such as carbon dioxide is no greater than may be expected from a gentle flowing stream such as the Ohio River.

Workers who have conducted experiments using fish as test animals for the evaluation of the toxicity of industrial wastes no doubt have encountered the problem of maintaining a sufficiently high concentration of dissolved oxygen in the test solutions. Unless the dissolved-oxygen concentration is at least 40 percent or 50 percent of saturation at the test temperature when mortality occurs, the test results are open to question. This minimum concentration is difficult to maintain during long periods, particularly if the test solutions have an oxygen demand, and a sufficiently large number of test animals (*i.e.,* 10 or more) is used in a conveniently small container.

It has been past practice to supply oxygen by aeration, *i.e.,* dispersion of small bubbles of compressed air through the solution by means of a diffuser. But if any volatile, toxic component is dissolved in the test solution, and air is bubbled through the solution, the toxic component will be "blown out" rapidly. The results of the test then will be worthless.

It was to determine when aeration could or could not be used that Hart, Doudoroff, and Greenbank (1945) introduced the rather long and tedious preliminary experiment to establish the presence or absence of volatile or unstable components. This test admittedly is difficult to perform, and very frequently at its conclusion the presence of volatile matter will have been established, with the result that oxygen must be supplied by means other than aeration.

What means to employ presents another problem, for the procedure must supply oxygen for test periods of 24, 48, or perhaps 96 hours. In the testing methods recommended by Hart, Doudoroff, and Greenbank (1945), adequate oxygen was obtained by starting the test with the dissolved oxygen at supersaturation levels. This procedure seemed

to be the best method yet devised, but it was neither satisfactory, biologically correct, nor always successful.

Pressure to simplify the testing methods, to eliminate the need for the lengthy preliminary examinations, and to avoid subjecting the test animals to supersaturation led to an intensive search for a more satisfactory method of introducing oxygen.

The fact that approximately five times as much oxygen can be dissolved in water from the pure gas than from compressed air was made the basis of the search. A piece of equipment was needed by which the pure oxygen could be placed in contact with the test solution and be dissolved with a minimum of agitation and with the test animals protected from the pure gas and harmful supersaturation. The first equipment tried was an inverted 6-inch funnel resting almost on the bottom of the test jar. The pure oxygen was introduced through the stem under just enough pressure to depress the solution in the funnel section about half, and form a circular interface about 3 inches in diameter. Fish were introduced with the thought that their activities would provide enough agitation outside the funnel to overcome the slowness of diffusion inside and set up a mechanical transfer of dissolved oxygen to all parts of the test solution.

It soon was discovered that this procedure was not going to be satisfactory. The dissolved-oxygen content in the test solution fell at practically the same rate as in an ordinary quiescent test, and the fish soon had to be removed to save them from suffocation. Apparently diffusion is so slow that it does not carry oxygen away from the interface at a rate which will prevent the formation of a saturated layer. After this layer forms, it acts as a tight valve and soon shuts off the solution of more gas. One thing was shown, however. If agitation outside the inverted funnel had so little influence on conditions inside, the reverse should be true and agitation on the inside could be employed to overcome the slowness of diffusion without affecting too seriously conditions on the outside.

Temporary equipment was devised to test this theory and a few tests served to confirm it. Oxygen could be introduced to all parts of the test jar by convection, and the standard number of test animals (10) maintained with the dissolved oxygen at saturation level. With this background a final design of equipment was developed and several units constructed so that experiments could be performed to determine the effect of the degree of agitation necessary to a satisfactory rate of oxygen introduction.

The apparatus is illustrated in detail in Figures 1, 2, and 3. Briefly it consists of a 6-inch funnel, the stem of which is extended upward (with the funnel inverted) as shown. Inside the funnel the stem is extended downward as a continuation of the funnel stem. Thus is formed a vertical tunnel for the shaft of the agitator. The shaft, which is driven from the top, rotates an impeller at the bottom.

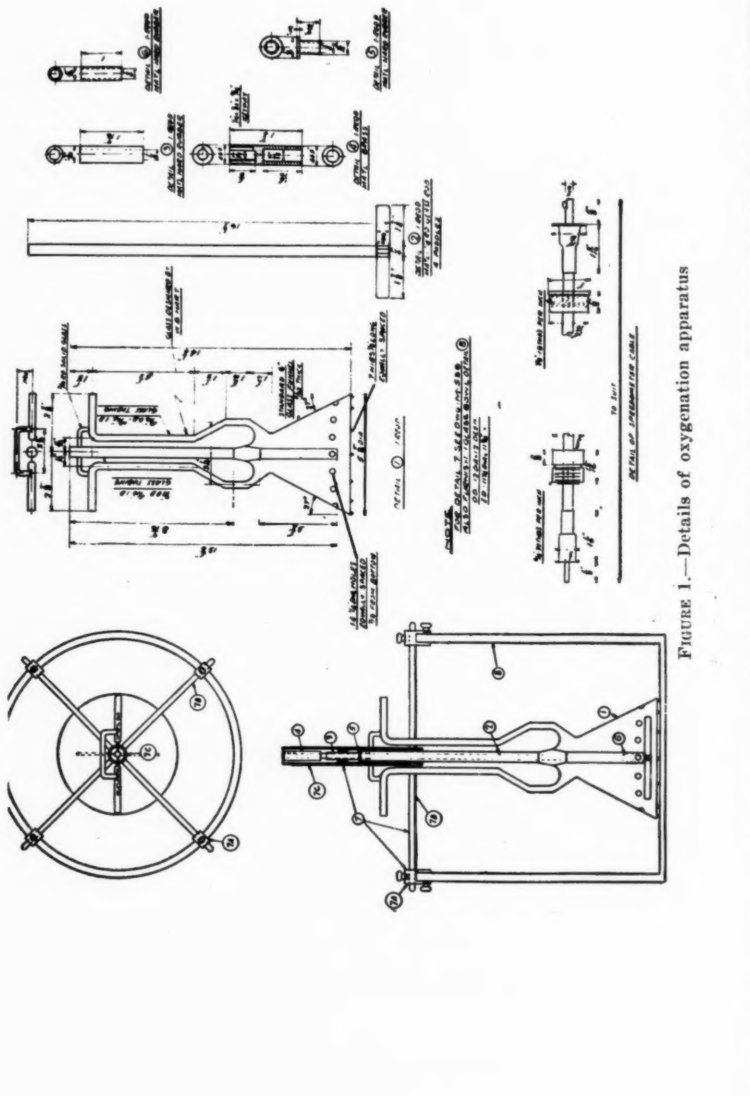

FIGURE 1.—Details of oxygenation apparatus

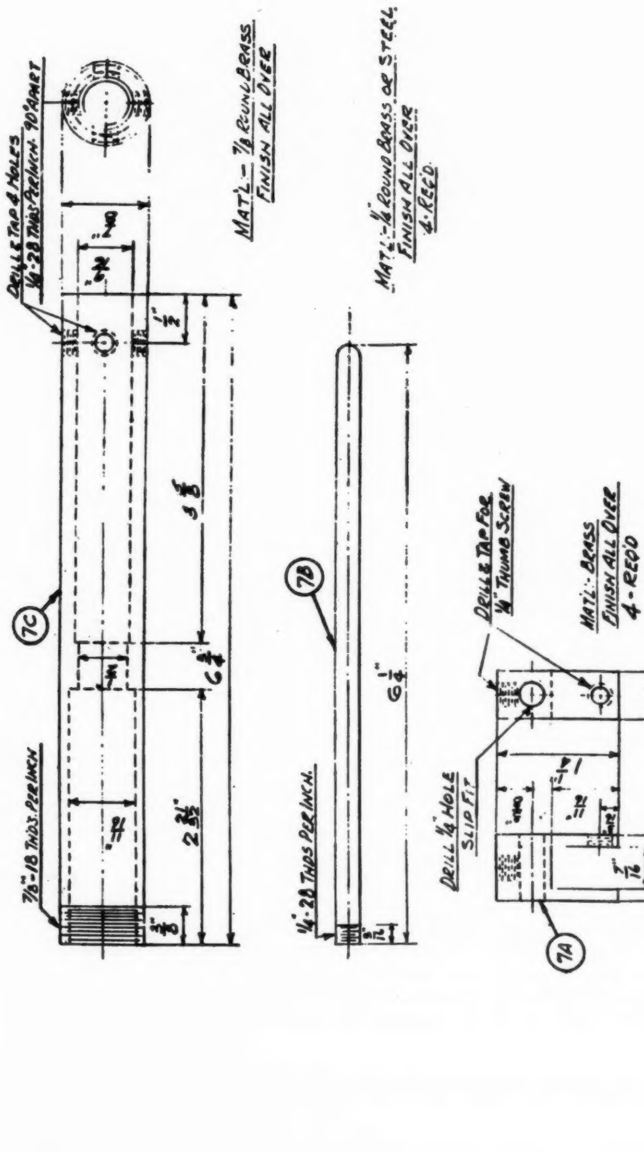

FIGURE 2.—Details of oxygenation apparatus—funnel support

FIGURE 3.—Closeup view of the oxygenation apparatus

It is suspended in the tunnel in such a way that the impeller moves in a plane just above the plane of the funnel edges.

Small beads of glass fused to the edge of the funnel hold the edge just off the bottom of the test jar. A row of holes around the funnel, just above the plane of the impeller, permits current to travel in through the holes, becomes partly saturated with oxygen by admixture with water which has been in contact with the pure gas at the interface, and pass out into that portion of the test solution occupied by the test animals. The current is produced by the rotation of the impeller. The direction of rotation appears to be of no importance.

Oxygen gas is introduced into the inverted cone of the funnel through a side arm. It is fed in as necessary under a very low, controlled pressure. A good form of needle valve is used following the pressure reducer on the gas bottle. A further control on the level of the solution-oxygen interface consists of a second side arm on the funnel carrying a fine capillary copper tube, which serves as a back-pressure valve. Its end can be immersed to various levels in water (*e.g.*, in the constant-temperature tank), thereby obtaining fine adjustment effect. Little gas need escape from the tube. The whole apparatus is held in the 12-inch-diameter by 12-inch-deep test jar by means of a bracket arrangement also shown in Figures 1 to 3.

The impeller shaft is operated by a speedometer cable driven by any particular type of drive which will provide the necessary rotation

rate. In the Waste Control Laboratory six cables are operated, each from a driven gear, which is one of a group of six surrounding a master driving gear. This gear is operated by a cable from a cone pulley, which in turn is belt-driven from a matched cone pulley. The latter is rotated through a reducing gear by a motor. All these mechanical features are shown in Figure 4. Variation in speed is accomplished by shifting the belt on the pulleys.

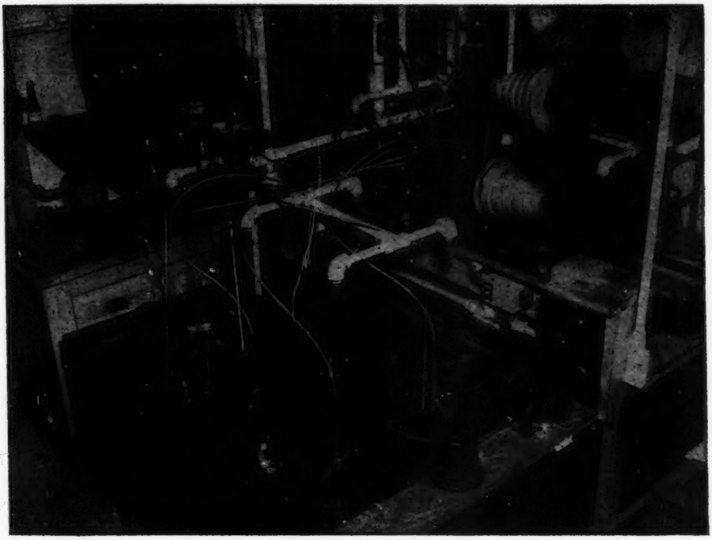

FIGURE 4.—View of the assembly of test jars, oxygenation apparatus, and agitation mechanism

With the equipment constructed, experiments were designed to test its effectiveness as an instrument for introducing oxygen without serious loss of volatile matter. To provide a drastic condition of a dissolved, volatile component, carbon dioxide at a concentration of about 85 p.p.m. was selected. Dissolved oxygen was maintained at high levels to minimize any toxic effect of the carbon dioxide on the test animals. All tests were carried out in triplicate and grouped in a series as an experiment.

In each test 15 liters of United States Mean Dilution Water were used as test solution. Carbon dioxide was introduced until a concentration of from 80 to 100 p.p.m. was present. The carbon dioxide was

determined by running pH and total alkalinity and comparing with curves which show the corresponding carbon-dioxide concentration (Betz and Betz, 1945). These results were compared with those obtained by direct titration with standard solution of sodium hydroxide. Oxygen was introduced by saturating the dilution water prior to use. Concentrations of 9 or 10 p.p.m. were used and checked by the usual Winkler method for dissolved oxygen. Samples for determination of carbon dioxide and dissolved oxygen were taken every half-hour or hour, as indicated by conditions. Consequently, the volume of test solution was reduced to about 12.5 or 13 liters at the end. All tests were carried out at 20° C.

Each experiment consisted of the following tests:

3 jars containing no fish, without the oxygenation equipment,
3 jars containing two fish, without the oxygenation equipment,
3 jars containing no fish, but with the oxygenation equipment,
3 jars containing five fish and the oxygenation equipment.

All fish used as test animals were bluegills (*Lepomis macrochirus*), about 60 millimeters in total length. Ten such animals previously had been kept in a test jar, using the oxygenation equipment at medium speed for almost one month.

TABLE 1.—*Loss of* CO_2 *and oxygen equilibrium for the oxygenation apparatus at medium speed and maximum interface*
[Each run is the average of triplicate tests. See Footnote 1 for definition of k]

Experimental conditions	Rate of loss of carbon dioxide (constant k per hour)		Dissolved-oxygen equilibrium (concentration, p.p.m.)	
	Run No. 1	Run No. 2	Run No. 1	Run No. 2
No fish, no oxygenation equipment........	0.0070	0.0040	11.9	8.0
Two fish, no oxygenation equipment......	0.0177	0.0201	6.3	5.6
No fish, oxygenation equipment..............	0.0417	0.0174	23.3	23.0
Five fish, oxygenation equipment............	0.0327	0.0412	19.1	16.4
No fish, minimum diffused aeration[1]......	....	0.51	....	8.4
No fish, maximum diffused aeration[2]......	....	2.00	....	8.4

[1]Minimum flow, one diffuser, 0.010 cubic feet per minute
[2]Maximum flow, one diffuser, 0.073 cubic feet per minute

Results of all tests have been plotted as curves in Figure 5 and recorded in Table 1. The data were analyzed to determine a rate-of-loss factor which could be compared with the rate of reaeration under quiescent conditions.[1] The results proved the equality of these rates. Because of this equality it is concluded that the relation between the loss of carbon dioxide and gain of oxygen will remain the same under conditions of very moderate turbulence, such as occurs when the oxygenation equipment is used in tests of toxicity.

[1]k is the coefficient of the rate of loss of CO_2 as defined by the equation:

$$\log \frac{E}{Eo} = -kt,$$

in which E = CO_2 content, in p.p.m. at any time t in excess of the CO_2 requirements for $CaCO_3$—CO_2 equilibrium,
Eo = E when t equals 0.0,
t = elapsed time in hours.

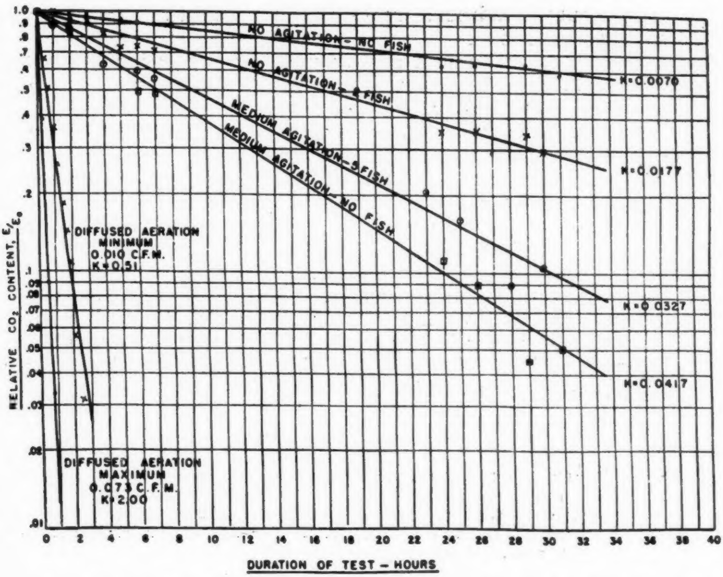

FIGURE 5.—The loss of carbon dioxide in reoxygenating test solutions. See Footnote 1 for a definition of terms

The value of k under the conditions of the various tests ranged from 0.0040 to 0.0417 at 20° C. These values then were compared with the monthly average values of k as determined by Streeter and Phelps (1925) for the Ohio River, a deep, sluggish stream of relatively little turbulence. For the Ohio River the values of k ranged from 0.0025 to 0.166, at 20° C., well below and above the values found in the tests. From this comparison it can be concluded that the loss of any volatile component in a toxicity test, as a result of the agitation used in the oxygenation equipment, will not be seriously great. Comparison with the conditions in the Ohio River (average $k = 0.050$; average velocity = 1.64 feet per second) indicates that on the average the loss in a toxicity test will be lower than in a natural stream, even one that is least conducive to loss of volatile matter.

Use of the equipment has been discussed with leading limnologists. Analysis of the conditions of its use shows that it provides a normal habitat condition for the test animals. The surface is exposed to the atmosphere so that there can be normal interchange of all gases (nitrogen, carbon dioxide, or oxygen). The only oxygen supplied is that necessary to maintain a saturated or nearly saturated solution.

No unnatural conditions traceable to the apparatus, when properly used, have been found.

In using the oxygenation equipment the test solution is prepared and the equipment placed in operation. Tests for dissolved oxygen are made as necessary. When the desired dissolved-oxygen level is attained the 10 experimental animals are introduced and the experiment is noted as started. The impeller is operated at from 30 to 50 revolutions per minute, and the interface is raised or lowered by pressure control as the oxygen determinations show to be necessary. Should the range of interface levels prove inadequate, a greater rate of agitation may be used, for the equipment as shown in the figures permits rates of from 15 to 90 revolutions per minute. Increased agitation should be avoided whenever possible, however. The toxicity test then is continued as usual. Many toxicity tests have been carried out conveniently and successfully in the Waste Control Laboratory, by means of the equipment, and its use is recommended for a variety of toxicity control and research investigations.

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THE LENGTH-WEIGHT RELATIONSHIP, FACTORS FOR CONVERSIONS BETWEEN STANDARD AND TOTAL LENGTHS, AND COEFFICIENTS OF CONDITION FOR SEVEN MICHIGAN FISHES

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Abstract

The factors for conversions between standard and total lengths are presented for the following Michigan fishes: bluegill (*Lepomis m. macrochirus*), yellow perch (*Perca flavescens*), pumpkinseed (*Lepomis gibbosus*), smallmouth black bass (*Micropterus d. dolomieu*), largemouth black bass (*Huro salmoides*), rock bass (*Ambloplites r. rupestris*), and the northern pike (*Esox lucius*). The ratio of standard to total length was found to increase progressively in all species as the length of the fish increases. The values of n in the length-weight equation, $W = cL^n$, which was derived for each of the species listed above, ranged from 2.969 for the rock bass to 3.199 for the pumpkinseed. When numbers of fish were large actual weights agreed well with those computed from the equation. Coefficients of condition (K in the metric system and C in the English system) are presented for the seven species.

The methods followed in the compilation and analysis of the data are described.

Introduction

The Michigan Institute for Fisheries Research has collected information on the game fishes of Michigan since 1931. These observations include the large numbers of weights and measurements of the bluegill, yellow perch, pumpkinseed, smallmouth black bass, largemouth black bass, rock bass, and the northern pike, that serve as the basis of the present report. Comprehensive data on conversion factors and length-weight relationship are not plentiful in the literature and yet this information has numerous practical applications in fishery work. The conversion factors presented in the present paper should aid in the comparison of works compiled on a basis of standard lengths and metric measurements with those based on total lengths and the English system. Length-weight relationships are useful in attempts to evaluate the condition of fish in particular waters. In the presentation of the data, the methods used to derive the formulas and to compute the factors are shown so that other workers may readily compare our observations with their own.

Specimens were collected for the most part by lake-inventory parties of the Institute. The various types of gear which were used included experimental gill nets, 5 by 125 feet, with five sections of different mesh sizes (ranging from 1½ to 4 inches, stretched measure, as manu-

factured); gill nets of single mesh size, 5 by 150 feet (meshes from 1½ to 4 inches, stretched measure); fyke and trap nets of various dimensions and mesh sizes; bag seines, 30 to 125 feet long; straight and "common-sense" seines, 6 to 50 feet long; and rod and line. Some samples were taken from sportsmen's catches by creel-census clerks. The specimens analysed in this study came from over 500 lakes located in all parts of Michigan.

Factors for Conversion between Standard and Total Length

In the original compilation of standard and total lengths, each millimeter of total length was made a column heading and each standard length was recorded in the appropriate column. Average standard lengths and total lengths were computed for 5-millimeter intervals of total length (except for the northern pike where 10-millimeter intervals were used). The ratio of standard to total length was determined for each of these intervals by dividing the average standard length by the average total length. For example, in the bluegill, 209 fish in the 120- to 124-millimeter group of total length, averaged 122 millimeters in total length and 96 millimeters in standard length. The value $96/122 = 0.786$ is the ratio for that group. Rate of change

Table 1.—*Factors for conversions between standard length (S.L.) and total length (T.L.), with and without changes in units, for seven Michigan fishes*

Species	Interval of total length (inches)	Number of fish	Conversion factors			
			T.L. to S.L. (same units)	S.L. to T.L. (same units)	S.L. (millimeters) to T.L. (inches)	T.L. (inches) to S.L. (millimeters)
Bluegill	under 5.1	2,335	0.782	1.278	0.0503	19.38
	5.1-8.1	3,712	0.793	1.261	0.0497	20.14
	over 8.1	1,253	0.803	1.246	0.0491	20.39
Yellow perch	under 4.0	422	0.833	1.200	0.0472	21.16
	4.0-7.8	3,610	0.847	1.181	0.0465	21.51
	over 7.8	1,569	0.852	1.174	0.0462	21.64
Pumpkinseed	under 4.7	843	0.794	1.259	0.0496	20.17
	over 4.6	1,460	0.807	1.239	0.0488	20.50
Smallmouth black bass	under 2.5	8	0.800	1.250	0.0492	20.32
	2.5-12.6	678	0.826	1.211	0.0477	20.98
	over 12.6	135	0.820	1.220	0.0480	20.83
Largemouth black bass	under 8.3	527	0.820	1.220	0.0480	20.83
	8.3-15.0	843	0.825	1.212	0.0477	20.96
	over 15.0	86	0.834	1.199	0.0472	21.18
Rock bass	under 5.8	1,066	0.789	1.268	0.0499	20.04
	over 5.7	925	0.802	1.247	0.0491	20.37
Northern pike	under 20.0	1,034	0.860	1.162	0.0458	21.84
	20.0-31.0	457	0.867	1.153	0.0454	22.02
	over 31.0	22	0.877	1.140	0.0449	22.28

in the ratio with increase in length was the basis for further combination into two or three larger intervals. The conversion factors recorded in Table 1 are the weighted means of the factors for the 5-millimeter intervals over the indicated range. Examination of the factors will show that as the fish increases in length the tail becomes relatively

shorter. This change has been observed frequently by others for a variety of species (Carlander and Smith, 1945), and is probably a characteristic of most species. As a convenience, factors were determined for conversions between standard and total lengths, with and without changes in units of measurement.

Length-weight Relationship

In the compilation of length-weight information the total lengths by 1-millimeter intervals headed columns and each weight was recorded under the proper length of fish. The average weight was then determined by 5-millimeter groups (except for the northern pike where 10-millimeter intervals were used). The standard length corresponding to the average total length for each 5-millimeter group was computed by use of the appropriate conversion factor, and the length-weight equation was fitted to the means of standard length (millimeters) and weight (grams) for intervals represented by 10 or more fish.

The equation used throughout was that of the general parabola, $W = cL^n$, where W = weight in grams, L = standard length in millimeters, and c and n are constants. According to Hile (1936) this general equation ordinarly gives a better result in the expression of the length-weight relationship than does the cubic parabola, $W = CL^3$, where W = weight in grams, L = standard length in millimeters, and C is a constant.

The equation, $W = cL^n$, expressed in logarithmic form becomes a straight line: $\log W = \log c + n \log L$.

The values of log c and n are easily determined by fitting a line to the logarithms of L and W. The values of log c and n are computed from the following formulas which are simply solutions of normal equations:

$$\log c = \frac{\Sigma \log W \cdot \Sigma (\log L)^2 - \Sigma \log L \cdot [\Sigma \log L \cdot \log W]}{N \cdot \Sigma (\log L)^2 - (\Sigma \log L)^2}$$

and

$$n = \frac{\Sigma \log W - N \cdot \log c}{\Sigma \log L}$$

As an illustration of the method that was found most convenient in compiling the length-weight data Table 2 is presented. This table is an excerpt from the original tabulation for the bluegill.

The values for log c and n for the species studied in this work are recorded in Table 3. By substituting these values in the logarithmic form of the equation $W = cL^n$, the calculated weights are determined.

TABLE 2.—*Excerpt from data on the bluegill to illustrate the method employed for the compilation of information on the lenght-weight relationship*
[The total and standard lengths are the averages for 5-millimeter intervals of the former measurement]

Total length	Standard length	Number of fish	Average weight (grams)	log L	log W	log L × log W	(log L)^2	Calculated log W	Calculated weight
127	99	135	35	1.9956	1.5441	3.0814	3.9824	1.5550	36
132	105	174	39	2.0212	1,5911	3.2159	4.0852	1.6346	43

TABLE 3.—*Values of log* c *and* n *in the length-weight equations for the seven species of Michigan game fishes*

Species	log c	n
Bluegill	—4.651316	3.11037
Yellow perch	—4.854310	3.05445
Pumpkinseed	—4.789026	3.19857
Smallmouth bass	—4.725066	3.05150
Largemouth bass	—4.625223	2.99278
Rock bass	—4.319450	2.96914
Northern pike	—5.223632	3.06647

Tables 4-10 contain the length-weight data for the seven species. These tables include total length in inches, standard length in millimeters, calculated weight in grams and ounces, and empirical weight in ounces to facilitate comparison of these data with other information. This information has also been put in graphical form (Figures 1-7). In general, the curves fit the data very well. The discrepancies that do occur can be attributed to the small numbers of fish at some intervals, to the fact that fish from many localities were combined, and to the circumstance that no separation was made of the data according to maturity, sex, or season or year of capture.

COEFFICIENT OF CONDITION

The coefficient of condition, K, was determined for the seven species by use of the following formula:

$$K = \frac{100{,}000\ W}{L^3}$$

where W = weight in grams,
and L = standard length in millimeters.

The coefficient of condition determined from actual average weights and lengths is subject to fluctuation particularly at lengths represented by small numbers of specimens. In order to smooth out these fluctuations the coefficients of condition, as presented in this paper, were calculated from the length-weight data. The equation used was:

$$\log K = a + m \cdot \log L,$$

where $a = \log c + 5$,
and $m = n - 3$.

Log c and n were obtained from the previous calculations of the length-weight relationship.

Because there has been a trend toward the use of the English system of weights and measures, the metric coefficient of condition has been converted into an English coefficient, C (based on total length in inches and weight in pounds), by use of the following equation:[1]

[1]This equation was presented by Dr. Hile at the Tri-State Fisheries Conference, held at Higgins Lake, Michigan, on February 14-15, 1946. It was published in the mimeographed minutes of the meeting which were distributed only to those present at the conference. The author extends his appreciation to Dr. Hile for permission to use his data, and for the many suggestions offered in the presentation of this paper. Klak (1940) gave the factor 0.02768 for conversions of C to K and suggested division by that figure for the reverse operation. The present author finds it more convenient to convert by multiplication than by division and hence prefers to convert K to C by means of the factor 36.1.

Table 4.—*The length-weight relationship and coefficients of condition of the bluegill in Michigan*

[See Table 3 for values of the constants in the length-weight equation and Figure 1 for a graphical representation of the length-weight relationship]

Number of fish	Total length (inches)	Standard length (millimeters)	Weight: Calculated (grams)	Weight: Calculated (ounces)	Weight: Empirical (ounces)	K (metric)	C (English)
24	1.4	29	1	0.04	0.04	3.23	56
45	1.7	33	1	0.04	0.04	3.28	57
56	1.9	37	2	0.07	0.07	3.32	57
42	2.1	41	2	0.07	0.07	3.26	58
37	2.3	45	3	0.11	0.11	3.39	59
41	2.4	48	4	0.14	0.18	3.42	59
42	2.7	52	5	0.18	0.21	3.45	60
25	2.8	56	6	0.21	0.25	3.48	60
26	3.0	60	8	0.28	0.35	3.50	60
30	3.3	64	9	0.32	0.35	3.53	61
39	3.4	68	11	0.39	0.42	3.55	61
61	3.6	72	13	0.46	0.49	3.57	62
59	3.8	76	16	0.56	0.56	3.59	62
122	4.1	80	18	0.63	0.63	3.61	62
109	4.2	84	21	0.74	0.74	3.64	63
87	4.4	88	25	0.88	0.85	3.65	63
100	4.6	92	29	1.02	0.95	3.67	63
137	4.8	95	32	1.13	1.13	3.68	64
135	5.0	99	36	1.27	1.23	3.70	64
155	5.2	105	43	1.52	1.38	3.72	67
174	5.4	109	48	1.69	1.55	3.74	67
215	5.6	113	54	1.90	1.76	3.75	68
189	5.8	117	60	2.12	2.01	3.77	68
221	6.0	121	67	2.36	2.26	3.78	68
217	6.2	125	74	2.61	2.50	3.80	68
182	6.4	128	80	2.82	2.68	3.81	69
183	6.6	132	88	3.10	3.00	3.82	69
168	6.8	136	96	3.39	3.35	3.83	69
162	7.0	140	105	3.70	3.63	3.84	69
176	7.2	144	115	4.06	4.20	3.86	69
172	7.4	148	125	4.41	4.48	3.87	70
214	7.6	152	136	4.80	4.97	3.88	70
191	7.8	156	148	5.22	5.26	3.89	70
182	8.0	160	160	5.64	5.71	3.90	70
163	8.2	166	179	6.31	6.14	3.92	73
197	8.3	170	193	6.81	6.52	3.93	73
142	8.6	174	207	7.30	7.05	3.94	74
103	8.8	178	223	7.87	7.79	3.95	74
88	9.0	182	238	8.39	8.29	3.96	74
91	9.2	186	255	8.99	8.96	3.97	74
82	9.3	191	277	9.77	9.59	3.98	74
47	9.5	194	291	10.26	10.05	3.99	75
27	9.7	198	310	10.93	10.90	3.99	75
11	10.0	202	330	11.64	11.78	4.00	75

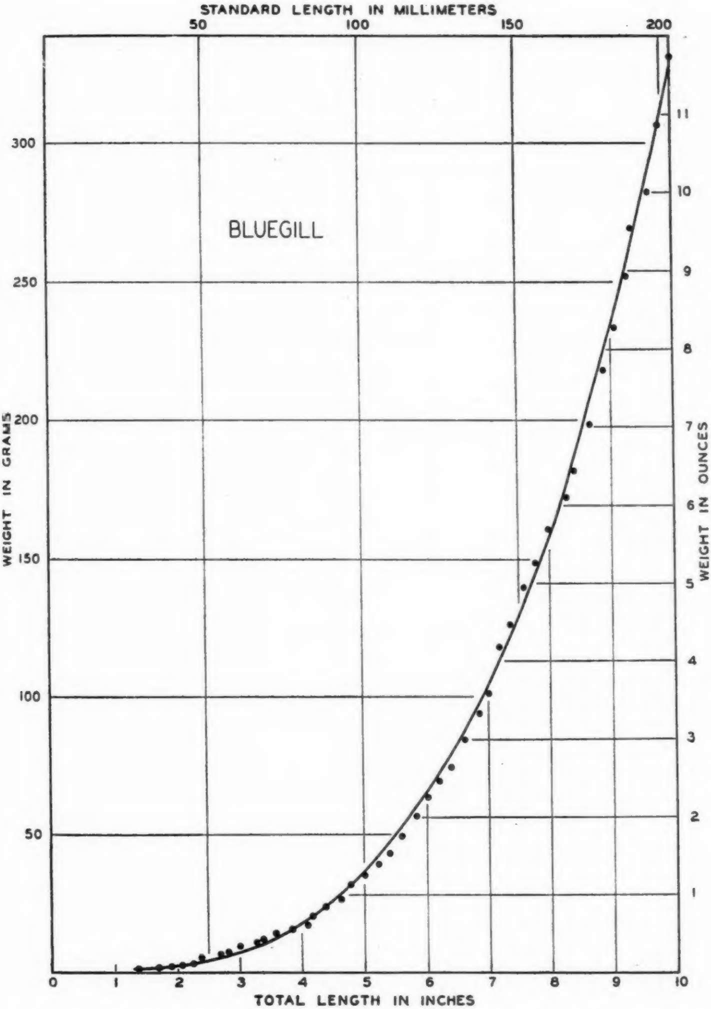

FIGURE 1.—Length-weight relationship of the bluegill. The curve is the graph of the length-weight equation, and the dots represent the empirical data.

TABLE 5.—*The length-weight relationship and coefficients of condition of the yellow perch in Michigan*

[See Table 3 for values of the constants in the length-weight equation and Figure 2 for a graphical representation of the length-weight relationship]

Number of fish	Total length (inches)	Standard length (millimeters)	Weight Calculated (grams)	Weight Calculated (ounces)	Weight Empirical (ounces)	*K* (metric)	*C* (English)
7	2.1	43	1	0.04	0.07	1.69	35
12	2.3	47	2	0.07	0.07	1.70	35
17	2.4	52	3	0.11	0.11	1.70	35
29	2.7	56	3	0.11	0.11	1.71	35
61	2.8	60	4	0.14	0.14	1.72	36
68	3.1	64	5	0.18	0.18	1.72	36
58	3.2	68	6	0.21	0.21	1.73	36
46	3.4	72	7	0.25	0.25	1.73	36
46	3.6	77	8	0.28	0.28	1.74	36
31	3.8	81	9	0.32	0.35	1.74	36
49	4.0	86	11	0.39	0.42	1.75	38
45	4.2	91	13	0.46	0.49	1.75	38
46	4.4	95	15	0.53	0.56	1.76	39
41	4.6	99	17	0.60	0.60	1.76	39
72	4.8	103	20	0.71	0.71	1.76	39
77	5.0	108	23	0.81	0.74	1.77	39
106	5.2	112	25	0.88	0.85	1.77	39
111	5.4	116	28	0.99	0.95	1.77	39
141	5.6	120	31	1.09	1.13	1.78	39
214	5.8	125	35	1.23	1.20	1.78	39
272	6.0	129	39	1.38	1.30	1.78	39
242	6.2	133	43	1.52	1.45	1.79	39
236	6.4	137	47	1.66	1.52	1.79	39
170	6.6	141	51	1.80	1.69	1.79	39
135	6.8	146	57	2.01	1.83	1.79	39
143	7.0	150	62	2.19	2.05	1.80	39
97	7.2	154	67	2.36	2.22	1.80	39
81	7.4	158	73	2.57	2.54	1.80	39
78	7.6	163	80	2.82	2.75	1.80	39
126	7.8	167	86	3.03	2.89	1.81	40
123	8.0	172	94	3.32	3.14	1.81	40
116	8.2	176	101	3.56	3.35	1.81	40
101	8.3	181	110	3.88	3.63	1.81	40
92	8.6	185	117	4.13	3.99	1.82	41
66	8.8	189	125	4.41	4.41	1.82	41
63	8.9	193	134	4.73	4.69	1.82	41
61	9.2	198	145	5.11	5.11	1.82	41
56	9.3	202	154	5.43	5.26	1.82	41
42	9.6	206	163	5.75	5.68	1.83	41
47	9.8	210	173	6.10	6.31	1.83	41
73	9.9	215	186	6.56	6.84	1.83	41
57	10.1	219	197	6.95	6.91	1.83	41
60	10.3	223	208	7.34	7.62	1.83	41
49	10.5	227	220	7.76	7.94	1.83	41
62	10.7	231	233	8.22	8.68	1.84	41
53	10.9	236	247	8.71	9.31	1.84	41
45	11.1	240	261	9.21	9.70	1.84	41
34	11.3	245	278	9.81	10.16	1.84	41
20	11.5	249	292	10.30	11.29	1.84	41
31	11.7	253	306	10.79	11.39	1.84	41
30	11.9	257	322	11.36	10.97	1.85	41
35	12.1	261	337	11.89	13.12	1.85	41
25	12.3	266	357	12.59	13.37	1.85	41
14	12.5	270	374	13.19	13.40	1.85	41
16	12.7	274	391	13.79	15.73	1.85	41
13	12.9	278	408	14.39	16.01	1.85	41
9	13.1	282	426	15.03	17.46	1.85	41
12	13.2	287	450	15.87	17.32	1.86	42
12	13.4	291	470	16.58	18.52	1.86	42

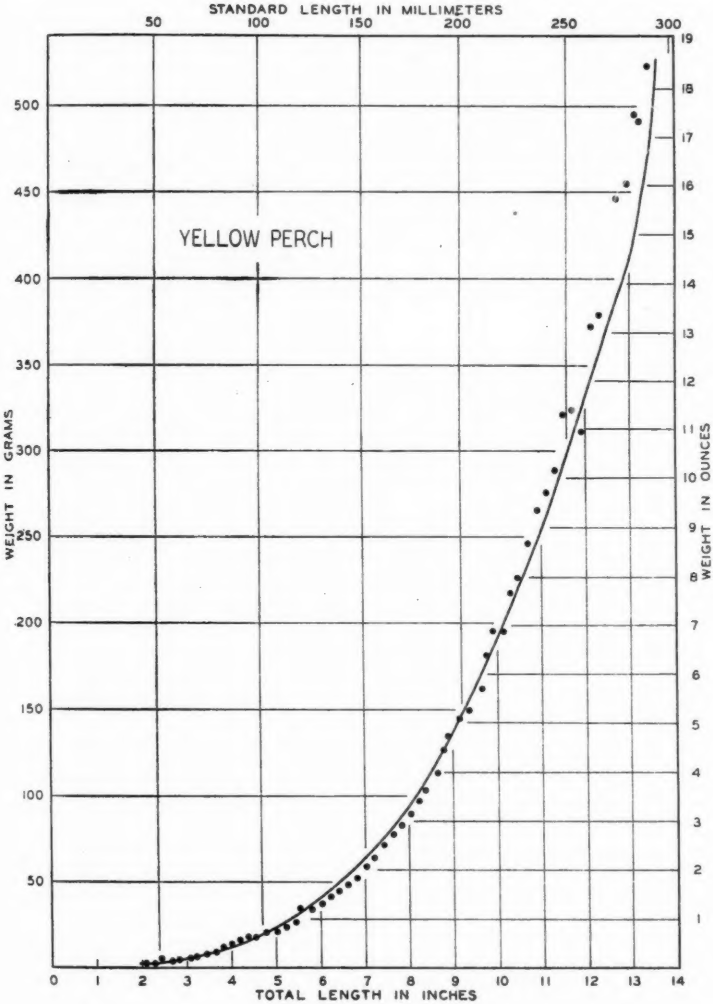

FIGURE 2.—Length-weight relationship of the yellow perch. The curve is the graph of the length-weight equation, and the dots represent the empirical data.

TABLE 6.—*The length-weight relationship and coefficients of condition of the pumpkinseed in Michigan*

[See Table 3 for values of the constants in the length-weight equation and Figure 3 for a graphical representation of the length-weight relationship]

Number of fish	Total length (inches)	Standard length (millimeters)	Weight: Calculated (grams)	Weight: Calculated (ounces)	Weight: Empirical (ounces)	K (metric)	C (English)
4	1.7	34	1	0.04	0.04	3.29	59
5	1.8	37	2	0.07	0.07	3.35	60
3	2.0	41	2	0.07	0.07	3.42	61
21	2.2	45	3	0.11	0.14	3.48	62
59	2.4	49	4	0 14	0.14	3.54	64
68	2.6	53	5	0.18	0.18	3.60	65
51	2.8	57	6	0.21	0.21	3.65	66
38	3.0	61	8	0.28	0.28	3.70	66
41	3.2	65	10	0.35	0.35	3.75	67
50	3.4	69	12	0.42	0.46	3.79	68
71	3.6	73	15	0.53	0.53	3.83	69
80	3.8	77	18	0.63	0.63	3.88	70
70	4.0	81	21	0.74	0.74	3.91	70
57	4.2	85	24	0.85	0.88	3.95	71
57	4.4	89	28	0.99	0.99	3.99	72
58	4.6	93	32	1.13	1.13	4.02	72
82	4.8	98	38	1.34	1.30	4.07	77
68	5.0	102	43	1.52	1.48	4.10	77
72	5.2	106	49	1.73	1.62	4.13	78
76	5.4	110	55	1.94	1.87	4.16	78
76	5.6	114	62	2.19	2.12	4.19	79
69	5.8	118	69	2.43	2.36	4.22	80
73	6.0	122	77	2.72	2.68	4.25	80
77	6.2	126	85	3.00	2.96	4.28	81
99	6.3	130	94	3.32	3.35	4.30	81
84	6.5	134	103	3.63	3.84	4.33	82
112	6.7	139	116	4.09	4.41	4.36	82
86	7.0	143	127	4.48	4.76	4.39	83
64	7.2	147	139	4.90	5.11	4.41	83
54	7.4	152	154	5.43	5.50	4.44	84
50	7.6	155	165	5.82	6.21	4.46	84
27	7.8	159	179	6.31	6.45	4.48	84
36	8.0	163	194	6.84	7.30	4.50	85
44	8.1	167	209	7.37	8.08	4.52	85
28	8.4	172	230	8.11	8.39	4.55	86
27	8.5	175	243	8.57	8.68	4.57	86
11	8.7	179	261	9.21	8.61	4.59	86
8	8.9	183	280	9.88	9.59	4.61	87
7	9.1	187	300	10.58	10.69	4.62	87
6	9.2	188	306	10.79	9.95	4.63	87
3	9.5	194	337	11.89	10.30	4.66	88

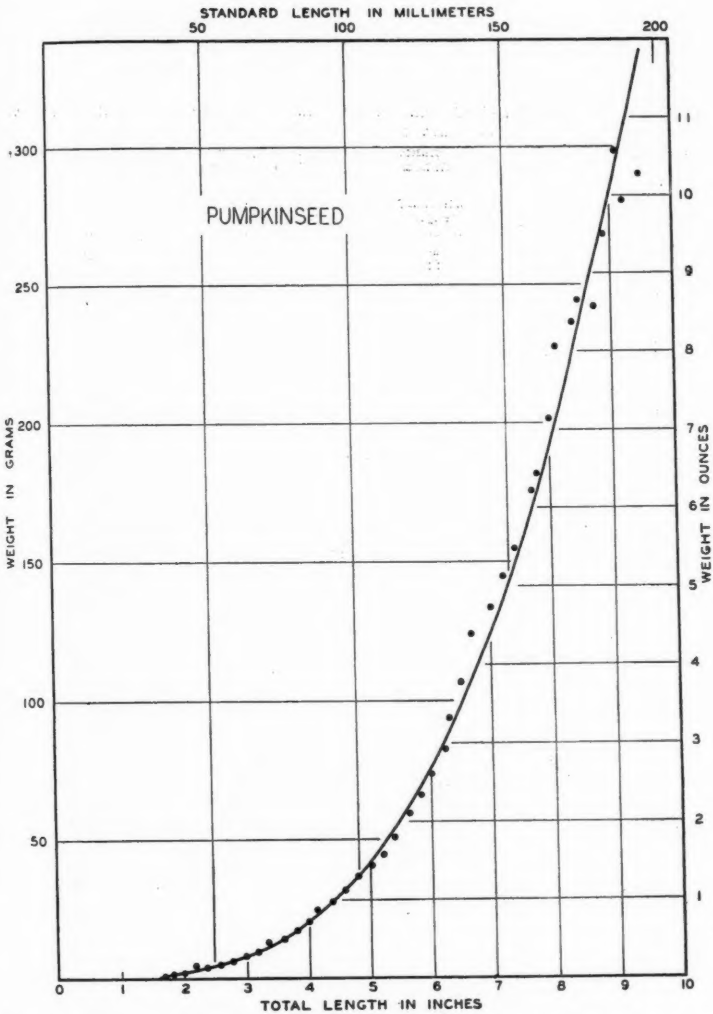

FIGURE 3.—Length-weight relationship of the pumpkinseed. The curve is the graph of the length-weight equation, and the dots represent the empirical data.

TABLE 7.—*The length-weight relationship and coefficients of condition of the smallmouth black bass in Michigan*

[See Table 3 for values of the constants in the length-weight equation and Figure 4 for a graphical representation of the length-weight relationship]

Number of fish	Total length (inches)	Standard length (millimeters)[1]	Weight Calculated (grams)	Weight Calculated (ounces)	Weight Empirical (ounces)	K (metric)	C (English)
3	2.1	44	2	0.07	0.07	2.29	42
2	2.7	55	4	0.14	0.13	2.32	47
2	3.0	63	6	0.21	0.19	2.33	48
6	3.3	71	8	0.28	0.32	2.35	48
2	3.8	80	12	0.42	0.43	2.36	48
8	4.2	89	17	0.60	0.59	2.37	48
9	4.5	95	21	0.74	0.79	2.38	49
6	5.0	105	28	0.98	1.00	2.39	49
7	5.4	112	34	1.19	1.24	2.40	49
7	5.7	119	41	1.44	1.39	2.41	49
3	6.1	127	50	1.75	1.75	2.42	50
6	6.5	136	61	2.14	2.07	2.42	50
10	6.9	144	72	2.52	2.58	2.43	50
8	7.3	153	87	3.05	2.84	2.44	50
7	7.7	162	104	3.64	3.72	2.45	50
11	8.1	169	119	4.17	4.19	2.45	50
8	8.5	175	131	4.59	4.66	2.46	50
25	8.8	184	153	5.36	5.45	2.46	50
28	9.2	193	178	6.23	5.99	2.47	51
76	9.7	201	203	7.11	7.25	2.47	51
94	10.0	204	228	7.98	8.04	2.48	51
85	10.4	218	257	9.00	9.04	2.49	51
74	10.8	226	289	10.12	9.78	2.49	51
52	11.2	233	318	11.13	11.27	2.49	51
23	11.6	242	355	12.43	12.26	2.50	51
33	12.0	250	393	13.76	13.48	2.50	51
22	12.4	259	436	15.26	14.98	2.51	51
9	12.8	265	470	16.45	17.36	2.51	50
16	13.2	275	525	18.38	17.39	2.52	50
15	13.6	283	572	20.02	19.76	2.52	50
18	14.0	291	625	21.88	21.60	2.52	50
16	14.4	298	668	23.38	22.94	2.53	50
10	14.8	306	727	25.45	24.46	2.53	50
14	15.1	315	792	27.72	29.45	2.53	50
12	15.4	321	840	29.40	30.29	2.54	51
12	16.0	339	991	34.69	34.16	2.54	51
15	16.4	339	998	34.93	37.94	2.54	51
4	16.8	351	1,106	38.71	42.24	2.55	51
13	17.1	356	1,150	40.25	41.48	2.55	51
5	17.5	362	1,216	42.56	41.64	2.55	51
6	18.1	372	1,319	46.17	47.33	2.55	51
3	18.5	393	1,570	54.95	55.33	2.56	51
2	19.0	401	1,658	58.03	60.24	2.56	51

[1]These data were originally compiled by 5-millimeter intervals but to facilitate printing were combined in 10-millimeter intervals.

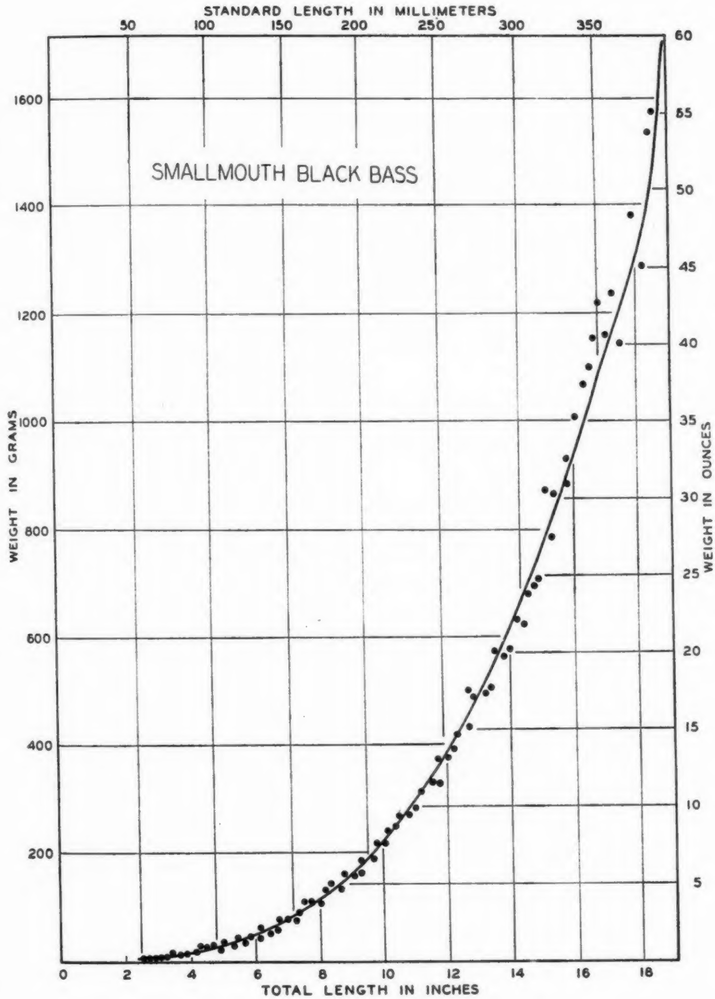

FIGURE 4.—Length-weight relationship of the smallmouth black bass. The curve is the graph of the length-weight equation, and the dots represent the empirical data

TABLE 8.—*The length-weight relationship and coefficients of condition of the largemouth black bass in Michigan*

[See Table 3 for values of the constants in the length-weight equation and Figure 5 for a graphical representation of the length-weight relationship]

Number of fish	Total length (inches)	Standard length (millimeters)[1]	Weight			K (metric)	C (English)
			Calculated (grams)	Calculated (ounces)	Empirical (ounces)		
18	2.2	46	3	0.11	0.09	2.31	46
19	2.5	53	3	0.11	0.14	2.30	46
19	3.0	61	6	0.21	0.20	2.30	46
27	3.3	71	8	0.28	0.27	2.30	46
28	3.7	78	11	0.39	0.37	2.30	46
17	4.1	88	16	0.56	0.53	2.29	46
16	4.5	95	19	0.67	0.67	2.29	46
25	4.9	104	25	0.88	0.87	2.29	46
24	5.3	110	31	1.09	0.98	2.29	46
24	5.7	119	39	1.37	1.27	2.29	46
17	6.1	127	47	1.65	1.64	2.29	46
14	6.5	136	58	2.03	1.88	2.29	46
19	6.9	144	68	2.38	2.37	2.29	46
30	7.3	153	81	2.84	2.97	2.29	46
34	7.7	160	94	3.29	3.25	2.28	45
35	8.1	169	110	3.85	3.88	2.28	45
33	8.5	177	126	4.41	4.54	2.28	46
38	8.8	186	148	5.18	5.22	2.28	46
39	9.3	194	167	5.85	6.01	2.28	46
36	9.6	201	187	6.55	6.35	2.28	46
40	10.0	211	215	7.53	7.56	2.28	46
47	10.4	218	238	8.33	8.23	2.28	46
56	10.8	228	271	9.49	9.26	2.28	46
69	11.2	237	305	10.68	10.72	2.28	46
82	11.6	244	331	11.59	12.07	2.28	46
67	12.0	252	365	12.78	13.41	2.28	46
44	12.4	261	403	14.11	14.33	2.28	46
30	12.8	269	445	15.58	16.26	2.28	46
22	13.1	278	488	17.08	16.31	2.28	46
23	13.6	284	523	18.31	19.68	2.28	46
17	13.9	294	581	20.34	19.92	2.27	46
18	14.4	304	641	22.44	23.02	2.27	46
11	14.8	312	691	24.19	26.73	2.27	46
11	15.2	316	718	25.13	27.37	2.27	47
12	15.6	328	803	28.11	33.03	2.27	47
6	16.1	346	944	33.04	35.32	2.27	47
7	16.3	348	963	33.71	37.45	2.27	47
5	16.6	353	1,003	35.11	37.38	2.27	47
6	17.1	362	1,108	38.78	44.12	2.27	47
6	17.4	371	1,116	39.08	45.59	2.27	47
6	18.0	389	1,336	46.76	47.01	2.27	47
3	18.3	392	1,369	47.92	60.95	2.27	47

[1]These data were originally compiled by 5-millimeter intervals but to facilitate printing were combined in 10-millimeter intervals.

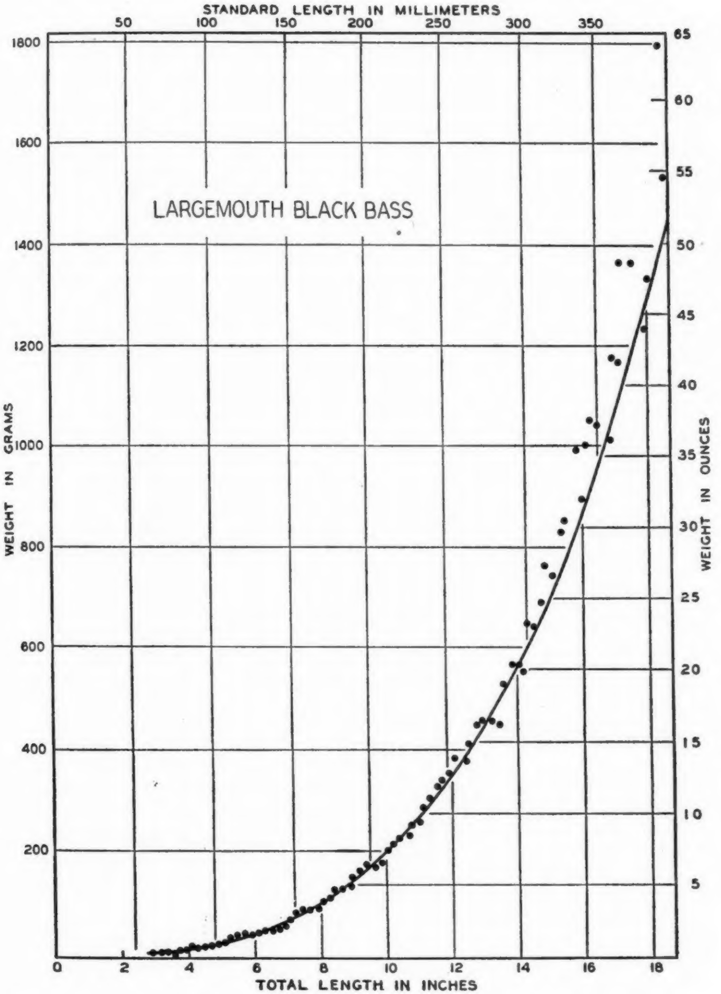

FIGURE 5.—Length-weight relationship of the largemouth black bass. The curve is the graph of the length-weight equation, and the dots represent the empirical data.

TABLE 9.—*The length-weight relationship and coefficients of condition of the rock bass in Michigan*

[See Table 3 for values of the constants in the length-weight equations and Figure 6 for a graphical representation of the length-weight relationship]

Number of fish	Total length (inches)	Standard length (millimeters)	Weight			*K* (metric)	*C* (English)
			Calculated (grams)	Calculated (ounces)	Empirical (ounces)		
5	1.5	30	1	0.04	0.04	4.32	77
2	1.7	33	2	0.07	0.04	4.32	77
1	1.8	36	2	0.07	0.11	4.30	76
2	2.0	42	3	0.11	0.14	4.28	76
3	2.3	46	4	0.14	0.14	4.27	76
2	2.4	48	5	0.18	0.14	4.26	76
3	2.7	54	7	0.25	0.21	4.25	75
4	2.8	57	8	0.28	0.32	4.24	75
5	3.1	61	10	0.35	0.35	4.23	75
9	3.2	65	12	0.42	0.42	4.23	75
9	3.4	69	14	0.49	0.49	4.22	75
24	3.6	73	16	0.56	0.60	4.21	75
49	3.8	77	19	0.67	0.63	4.21	75
79	4.1	80	21	0.74	0.74	4.20	74
71	4.2	84	25	0.88	0.88	4.19	74
56	4.4	88	28	0.99	0.95	4.19	74
57	4.6	92	32	1.13	1.13	4.18	74
50	4.8	96	37	1.30	1.30	4.18	74
47	5.0	100	41	1.45	1.45	4.17	74
68	5.2	104	47	1.66	1.69	4.17	74
97	5.4	108	52	1.83	1.83	4.16	74
54	5.6	112	58	2.05	2.12	4.16	74
53	5.8	116	65	2.29	2.36	4.16	74
46	6.0	122	75	2.65	2.54	4.15	77
70	6.2	126	83	2.93	2.89	4.14	77
66	6.4	130	91	3.21	3.10	4.14	77
72	6.6	134	99	3.49	3.39	4.14	77
62	6.8	138	108	3.81	3.63	4.13	77
53	7.0	142	118	4.16	4.02	4.13	77
34	7.2	146	128	4.51	4.41	4.13	77
35	7.4	150	139	4.90	4.73	4.12	77
35	7.6	154	150	5.29	5.22	4.12	77
36	7.8	158	162	5.71	5.47	4.12	77
45	8.0	162	174	6.14	5.85	4.11	77
27	8.2	166	187	6.60	6.52	4.11	77
24	8.3	170	201	7.09	7.27	4.11	77
18	8.6	174	215	7.58	7.87	4.10	76
13	8.8	178	230	8.11	7.87	4.10	76
13	8.9	182	246	8.68	8.50	4.10	76
10	9.2	186	262	9.24	9.77	4.10	76
14	9.3	190	280	9.88	9.52	4.09	76
15	9.5	194	297	10.48	11.18	4.09	76
23	9.7	198	312	11.00	11.67	4.09	76
18	9.9	202	335	11.82	12.03	4.09	76
13	10.1	205	350	12.34	12.77	4.08	76
14	10.3	210	376	13.26	13.09	4.08	76
17	10.5	213	392	13.83	15.06	4.08	76
5	10.7	217	414	14.60	14.07	4.08	76
5	10.9	221	437	15.41	16.82	4.07	76
5	11.1	226	467	16.47	15.84	4.07	76
2	11.3	231	500	17.64	18.48	4.07	76

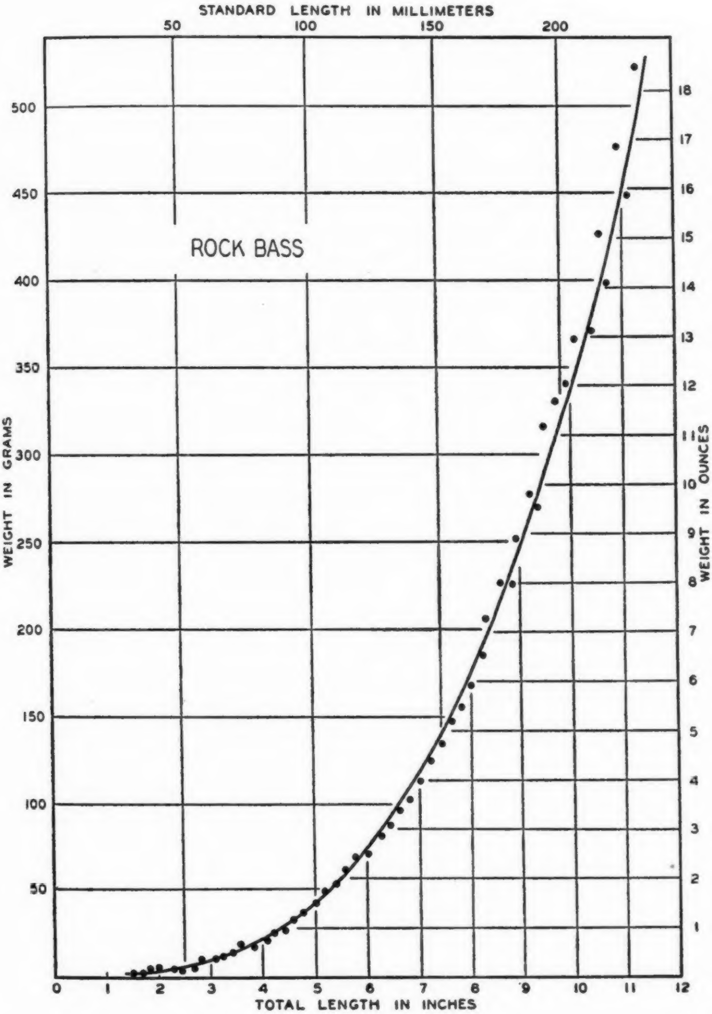

FIGURE 6.—Length-weight relationship of the rock bass. The curve is the graph of the length-weight equation, and the dots represent the empirical data.

TABLE 10.—*The length-weight relationship and coefficients of condition of the northern pike in Michigan*

[See Table 3 for values of the constants in the length-weight equation and Figure 7 for a graphical representation of the length-weight relationship]

Number of fish	Total length (inches)	Standard length (millimeters)[1]	Weight			K (metric)	C (English)
			Calculated (grams)	Calculated (ounces)	Empirical (ounces)		
16	2.7	59	1	0.04	0.04	0.78	18
9	3.4	75	3	0.11	0.09	0.80	18
5	4.4	96	7	0.25	0.32	0.81	19
5	5.1	111	12	0.42	0.50	0.82	19
2	6.0	129	19	0.67	0.69	0.83	19
4	6.6	143	25	0.88	1.08	0.83	19
15	7.4	163	36	1.26	1.37	0.84	19
16	8.2	179	49	1.72	1.84	0.84	19
32	9.0	197	65	2.28	2.08	0.85	20
37	9.8	215	84	2.94	2.64	0.85	20
16	10.5	230	105	3.68	3.49	0.86	20
13	11.5	252	138	4.83	4.74	0.86	20
23	12.2	267	165	5.78	5.65	0.87	20
42	13.0	283	197	6.90	6.65	0.87	20
63	13.8	302	239	8.37	8.12	0.87	20
83	14.6	318	282	9.87	9.77	0.88	20
73	15.4	336	333	11.66	11.11	0.88	20
79	16.2	352	385	13.48	13.04	0.88	20
44	16.8	367	436	15.26	15.87	0.89	20
46	17.7	386	508	17.78	18.82	0.89	20
63	18.4	402	579	20.27	20.58	0.89	20
57	19.3	420	663	23.21	23.86	0.89	21
57	20.0	440	763	26.71	26.92	0.90	21
70	20.7	456	852	29.82	30.93	0.90	21
49	21.4	472	946	33.11	34.19	0.90	21
47	22.4	493	1,081	37.84	37.79	0.90	21
31	23.2	511	1,209	43.32	42.82	0.90	21
31	23.9	527	1,327	46.45	45.95	0.91	21
25	24.7	544	1,460	51.10	51.17	0.91	21
19	25.6	564	1,640	57.40	54.85	0.91	21
14	26.2	577	1,754	61.39	60.82	0.91	21
12	27.1	597	1,944	68.04	67.42	0.91	22
9	27.8	615	2,129	74.52	76.90	0.92	22
8	28.9	635	2,344	82.04	81.68	0.92	22
6	30.1	653	2,561	89.64	84.83	0.92	22
7	30.9	672	2,791	97.69	91.09	0.92	22
10	31.7	697	3,131	109.59	106.13	0.92	23
3	32.7	727	3,562	124.67	136.65	0.93	23
4	34.2	763	4,118	144.13	140.75	0.93	23
4	35.2	783	4,472	156.52	158.27	0.93	23
2	38.0	845	5,633	197.16	226.54	0.94	23
2	40.3	897	6,777	237.20	237.93	0.94	23

[1]These data were originally compiled by 10-millimeter intervals but to facilitate printing were combined in 20-millimeter intervals.

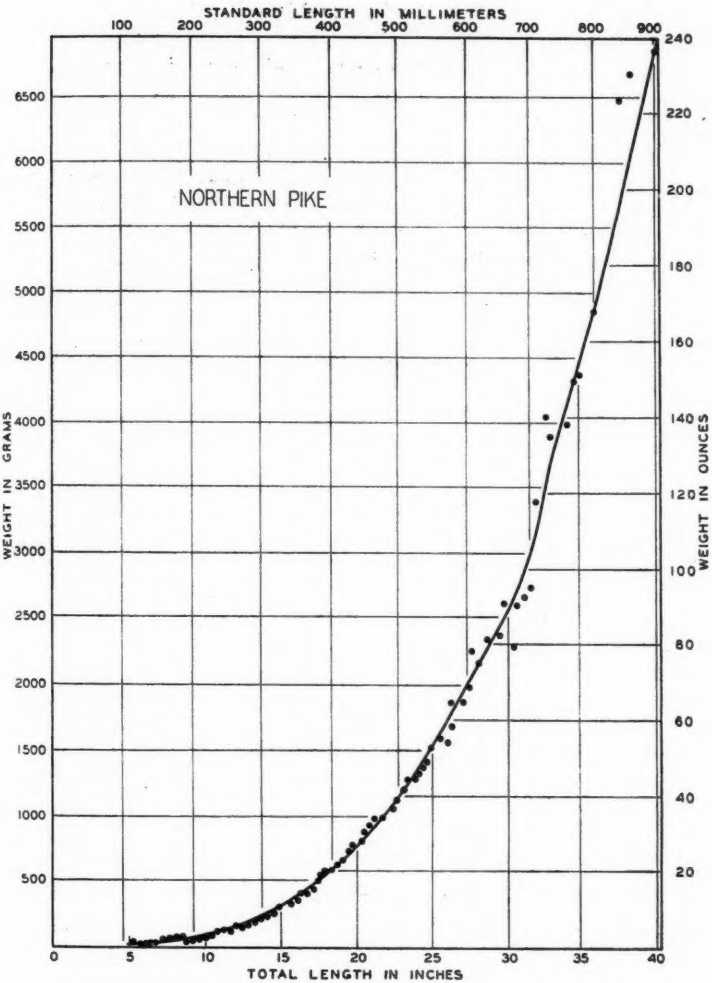

FIGURE 7.—Length-weight relationship of the northern pike. The curve is the graph of the length-weight equation, and the dots represent the empirical data.

$C = 36.1\ r^3\ K_m,$

where r = ratio of standard to total length,

and K_m= coefficient of condition in the metric system.

Tables 4-10 contain the data on the coefficients of condition.

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FRESHETS AND FISH

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Abstract

The action of freshets on the runs of fishes in streams has been long known to man, but has never been scientifically studied.

Angling for Atlantic salmon in the Margaree River, Cape Breton, was found to be dependent upon entrance of the fish from the sea which required heavy freshets. These freshets in 1935 made an abrupt transformation in fish present and in angling. In comparison with the neighbouring Cheticamp River, the tendency of the fish to enter chiefly late in the season, months after they had appeared on the coast, has been related to the difficulty for the salmon to enter through the strongly tidal estuary mouth until heavy rains come in the fall.

Experiments with sharp, but not large artificial freshets in the Moser River, Nova Scotia, gave double the expected number of both salmon and brook trout entering from the sea and gave good angling when the temperature was not too high. There is evidence that at all stages salmon respond more or less to freshets by ascent of streams. Ascent occurs chiefly as the freshet is subsiding. Descent of salmon at all stages occurs with freshets but chiefly at the height of the freshet.

The phenomenon is a general one and is probably not confined to fishes. In essence, it is the response of the organisms to displacement over the solid substratum by the fluid medium. In the fish, it is part of the rheotactic response, effected through sight, contact with the bottom and possibly the action of turbulences on the lateral line organs. Freshets effect migration of fish through such a stimulus to ascent, through carrying the fish down stream, and through breaking up the "homes" of the individual fish.

Introduction

From time immemorial it has been common knowledge that the runs of certain stream fishes are more or less definitely associated with floods, freshets, or spates. The basis for this relationship seems never to have been seriously investigated. Whatever may have been observed and recorded, and I have made no attempt to search the enormous literature on fishes for references to the phenomenon, the order in this association between freshets and movement of fishes has not been incorporated in the body of scientific knowledge to permit accurate prediction of fish behavior.

In my boyhood in the Niagara peninsula, my grandfather operated the pioneer saw-mill that had been built by his father on a branch of the Twenty (20 miles from the Niagara River) Creek. He sawed logs into lumber with water power from water stored in the mill pond, and the freshet produced in the creek below brought up suckers (*Catostomus*) in the spring to the mill and left them concentrated

just below it when the water subsided on closure of the gate in the dam. Sometimes it was possible to shovel the suckers out of the small stream. The Fishery Regulations for Eastern Canada contain a clause that illustrates how generally the action of freshets has been appreciated. It reads "no person shall use a dam for the purpose of so regulating the retention or discharge of water as to facilitate the catching of salmon, either by suddenly closing or opening the dam, or in any other manner whatsoever."

Ascent and Angling

In 1934, the Fisheries Research Board of Canada was asked by the anglers of Cape Breton Island to assure salmon in the Margaree River. Enquiry revealed that planning for angling was being based to quite an extent upon rise in the river from rainfall; and records of numbers of salmon taken by angling as reported by the Inspector of Fisheries, Mr. A. J. Murphy, during the previous decade showed good correlation with volume of river discharge as recorded by the Dominion Hydrometric and Power Bureau. During extensive investigations over the river system in 1935, a most striking transformation in numbers of salmon in the river and angling success was observed (Huntsman, 1939).

The dearth of salmon in the river but not outside the estuary mouth, which had prevailed from the beginning of the season in June, ceased abruptly following heavy rains in late August. The discharge of the virtually lakeless Northeast branch rose from 94 second-feet (cubic feet per second) on August 21 to 2,070 second-feet on August 25, while in the Southwest branch, which arises from the 12-mile-long Lake Ainslie, the discharge rose from 55 to 278 second-feet only. As the freshet rapidly subsided, large numbers of salmon were taken, starting at the head of tide (best on the second day) and progressively farther up, with the best fishing 12 miles up on the Northeast branch occurring throughout the second week. No salmon were caught in the Southwest branch. Plans made from a survey in 1936 to provide similarly large artificial freshets from Lake Ainslie in order to assure salmon in the river for angling early in the season were not proceeded with because the cost was considered too great.

The apparent need for *heavy* freshets to bring salmon in from the sea seemed to be a peculiarity of the Margaree River, since the neighbouring Cheticamp River had its angling best at the beginning of the season in June and progressively poorer from then on, while the angling of the Margaree was the reverse. The explanation was seen to lie in the character of the estuary mouth. From the shallow mouth of the Cheticamp estuary, river water pours most of the time, while from the narrow mouth of the Margaree estuary, deepened enough to have maximum scouring effect of tidal interchange for maintaining a passageway for vessels, river water issues only with ebbing tide to

flow away along the coast and to be replaced by an inflow during flood tide of full salt water. Deepening of the mouth through a period of more than 60 years had clearly made it more difficult for the salmon to enter without big freshets, which on the whole come late in the season with the sun low and the demands of land plants for water largely over.

Artificial freshets or "spates" to bring salmon up from the sea had been used previously. In 1888 on the Grimersta River in Scotland as described by Calderwood (1921) water was let down from Loch Langabaht into the lowest of a chain of four lochs, where it was held by constructing a 6-foot dam at the mouth. When the dam was then broken on August 22, the salmon, that had been congregated at the head of tide for a long time in a very dry season, swarmed up the river and into the loch, but did not go farther up until rains came at the end of the month, by which time over 400 salmon had been taken by three rods, one rod taking 54 in a single day. This experiment proved that water fresh from the sky was not necessary, as had been maintained, and also illustrated the advantage for angling of having the fish concentrated rather than dispersed throughout much water. In spite of this success, regular use of artificial freshets failed to develop, doubtless because the procedure actually followed on the Grimersta is rather troublesome, rarely feasible, and perhaps seldom required.

The Moser River of outer Nova Scotia was selected in 1938 for study and experiment with artificial freshets since it offered the possibility of inexpensive control of water discharge and also simpler conditions for salmon entrance. However, temperature (sometimes reaching lethal heights as reported for 1937 and studied in 1939) proved to be the chief deterrent for successful angling. By 1942, a background of experience and proper integration of the work with local interests permitted in a very dry season a test of the effectiveness of artificial freshets made from Round Lake, 8 miles up from the river mouth, with three fences for counting moving salmon situated at the head of tide, ¾ mile up (head of village) and 4 miles up (Salmon Hole), respectively (Fig. 1). With many fish in the estuary, three sharp freshets in the last five days of July seemed to take nearly all the fish up. The great majority went up with the first freshet, the numbers for the three being 367, 140 and 23, respectively. Similarly, after 10 days' rest three more freshets seemed to take up the smaller number that had accumulated in the interim, most going up with the first freshet In each trial, the numbers ascending at the Salmon Hole, 4 miles up, increased with successive freshets rather than decreased. More than 1,400 salmon entered the river, which was twice as many as were expected from the experience of the previous three years. Over 1,300 brook trout (*Salvelinus fontinalis*) ascended the river, about twice as many as were expected from the number descending in the spring and from previous experience of the proportion returning. This result

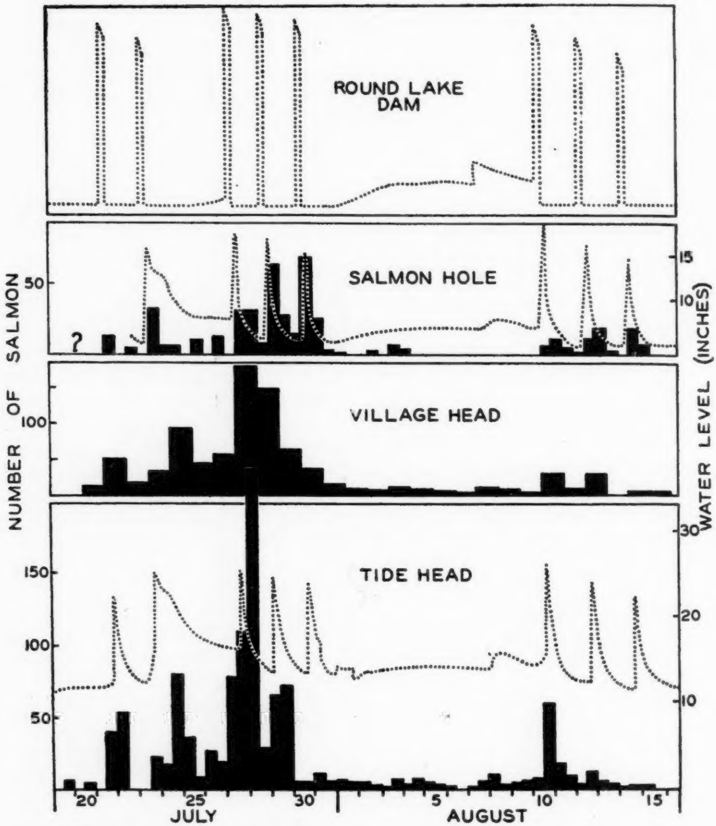

FIGURE 1.—Salmon ascent with artificial freshets during drought, Moser River, Nova Scotia. Histograms show numbers of salmon and the dotted lines the water levels. Head of village—¾, Salmon Hole—3½, and Round Lake dam—8½ miles above head of tide.

suggests that the artificial freshets were so effective as to bring in wandering salmon and trout from other rivers in addition to the native stocks. Rise and fall seemed to be too abrupt near the dam, since the salmon quickly went up half way but failed to reach the dam. A long, low freshet had little effect. The nature of the most effective type will doubtless depend upon where the fish are, the conditions in the water and what is wanted. After being stimulated by the

freshet, the salmon ascended even when the water level was very low. The temperature had risen so high by the time (July 21) the freshets were first made that very few fish were taken by angling, and some died.

In 1943, the freshets were started early in an effort to take the salmon up while the temperature was still low enough for good angling. They were begun early in June when the salmon were first being taken at the mouth of the estuary. Three times as much rain fell as in 1942. From June 10 when the first salmon entered the river until July 8 when heavy rains swept away two of the counting fences, there were but slight natural freshets in spite of a rainfall of 6.5 inches. A sharp though slight artificial freshet was made every few days. The run developed steadily, reaching an average of more than 30 fish per day for the last 10 days. By July 8, when counting became impossible, 474 salmon had entered the river and 25 percent of them had already been taken by angling. Many more salmon and more of the large salmon, which are at the estuary mouth only early in the season, had ascended the river by that date than in any of the previous four years, and over three times as many as the average had gone up stream, in spite of an unusually late season. Although (1) it was early in the season, (2) the water was high, and (3) the temperature was low, there was but little and delayed movement of the fish through the fence at Salmon Hole. Since the smolts descending the river had been marked in 1942, any unmarked grilse were presumed to be of foreign origin; these formed 25 to more than 50 percent of the grilse that entered the river.

With freshets as the outstanding and controlled factor, other factors affecting ascent of salmon became evident from continuous observations made at the counting fences, chiefly the lowest one. While the fish began to ascend as the freshet developed, the principal ascent was when the freshet was subsiding rapidly. With shallow water, fish ran chiefly for an hour or so after dusk, with numbers diminishing during the night, and ascent stopping somewhat abruptly at sunrise. With the temperature rising above 65° F., there was a decreasing proportion of upward movement, although the amount of movement (down as well as up) was greater, at least between 70° and 75°. Traps that permit movement only in one direction fail to distinguish between to-and-fro movement and definite ascent or descent of the fish.

There has been rather general belief that, no matter where the salmon may be, they know when their native rivers are in proper condition for ascent and proceed to them at that time. Menzies (1916) found in fishing bag nets on the coast of Scotland that with floods in the rivers the take dropped to nothing. He has concluded (1937) "that salmon seem to know when a natural flood prevails, for they will desert a stretch of coast where, during dry weather, they may be caught freely, and which is many miles from a river. In such positions, however, they cannot be expected to realize the existence of an

'artificial' flood resulting from the release of stored water." Coston, Pentelow, and Butcher (1936) stated that salmon in an estuary without a freshet go "no farther, because instinct tells them there is not sufficient water to give them free passage above" and that "the salmon instinctively knows that a rush of water means a spate and a clear passage and off he sets without a doubt in his mind as to the cause of the spate." It may be quite misleading to presume to know what is in the mind of a salmon.

During the fishing season from June to August, salmon taken, tagged and released in Minas Channel, Bay of Fundy, far from salmon rivers behaved very differently in 1946 from what they did in 1945. With heavy rain in 1945, they went, not oceanward, but as far as 70 miles to rivers or their estuaries, but, with drought in 1946, they went, not riverward, but oceanward to the mouth of the Bay as far as 100 miles. Salinity determinations showed, however, that they were exposed in the channel to a very definite gradient in amount of river water, and their response depended doubtless upon its sharpness, which would be greater after heavy rains.

Neither in the Margaree River nor in the Moser River was there at any time too little water for easy ascent of the fish. No basis can be seen for the belief that the fish require high water to ascend, except that with high water they will ascend during the day as well as at night. Fish like salmon, that leap falls, can and do ascend streams so shallow that much of their bodies are above the surface.

It should be evident that the salmon move in response to a stimulus. A change in river discharge clearly acts as a stimulus to salmon in an estuary or in a river. Chidester (1922) found that *Fundulus heteroclitus* responded to "stream pressure" by going into the discharged water irrespective of other factors, such as toxic substances and salinity. We lack precise knowledge as to the conditions under which a salmon requires a stimulus of given strength for it to ascend a given rapid and what constitutes such a stimulus. We should not take it for granted that the salmon knows where it wants to go and goes there. Nor should we conceal ignorance by using the word "instinct."

It is not only the salmon that are maturing sexually that are stimulated by freshets to ascend. Salmon kelts liberated in the Margaree estuary in the fall were caught upriver the following spring when there were sharp freshets or rapidly lowering discharge shortly after they were liberated (Huntsman, 1938). Salmon parr were found to ascend small tributaries of the main Margaree River and of its estuary (Huntsman, 1945b). This movement was clearly a response to the turbulent outflows of these streams and would doubtless have been accentuated by freshets, although data on this point are lacking. There is also evidence that smolts ascend streams, but whether they ever do so as a result of stimulation by a freshet is not known.

Increased Activity

There is evidence that freshets make the fish more active apart from ascent. In 1937, the course of the Margaree fishery showed clearly that a freshet far up the Northeast branch produced immediately a spurt of good angling without particular change in either discharge or angling down near the river mouth (Huntsman, 1939). This fact indicated that freshets will act on fish already in the river to give angling.

When starting study of Moser River in 1939, we operated a small dam at the mouth of Mill Lake to test the action of a small freshet on the river below. With salmon present, successful angling, which had ceased when the temperature rose during the forenoon, was brought back by a small freshet at noon. The fish were observed cruising from pool to pool after the freshet came.

Descent

While a freshet stimulates salmon to ascend the stream, its stronger current tends to prevent their ascent or carry them down stream. This opposition of effects serves to explain the fact that the fish ascend when the freshet is subsiding rather than when it is at its height. That a strong freshet carries maturing salmon down stream is evidenced by the fact that Menzies (1916) found that most of the salmon taken on the coast following floods in the rivers were such as had clearly been in rivers for some time as shown by their condition (such fish are known as "droppers"). Results from the tagging of salmon kelts (Huntsman, 1945a) have shown that when heavy floods followed their liberation they were in subsequent years distributed farther seaward, whether they were liberated far up a river, in its lower part, or in the estuary. Also, when they were liberated just outside an estuary, like the St. John, they entered it and remained therein unless heavy floods prevailed, when they were found to be distributed outside in subsequent years.

Berry (1932, 1933) and White and Huntsman (1938) found that an important factor for descent of smolts was rise in water level, that is, freshets. Descent occurs in the spring when the temperature has risen sufficiently from the low level of winter and it is chiefly at night. Although precise counts are lacking, the movement clearly reaches its peak with the peak of the freshet if the supply of fish lasts, thus differing from the ascending movement. There is also some descent of salmon parr with freshets (Huntsman, 1945b), the amount clearly dependent upon the size of the freshet.

Generality of Effect

Although salmon on the whole remain in one locality at certain stages in their life history, descend streams at others, and ascend at

still others, they are affected by freshets at all stages and move both upwards and downwards at all stages. Also such behaviour occurs in the so-called non-migatory salmon that remain in fresh-water throughout their lives as well as in those that migrate to the sea. In fact, no hereditary differences between such fish have yet been demonstrated.

In the Moser River experiments, the brook trout (*Salvelinus fontinalis*) were affected by freshets similarly to the salmon (details are still to be worked out). These brook trout were fish that had been in the sea for several months (White, 1941) and were the usual silvery "sea trout." That the behaviour of this species, where it does not migrate to the sea, and lives wholly in fresh-water streams is similar is evident from tagging experiments in Pennsylvania streams by Watts, Tremblay, and Harvey (1942) who found that the fish made their chief migrations after rains and with rises in water, whether upstream in the spring or upstream and downstream in the fall.

The sucker (*Catostomus commersonnii*) is found ordinarily in salmon streams of eastern Canada and it passes its entire life therein, descending into estuaries but only so far as the salinity remains quite low. This species also shows essentially the same behaviour as the salmon in relation to freshets.

The shad (*Alosa sapidissima*), which spawns in rapids of the more sluggish of these fresh-water streams and seems to require the sea for most of its growth, behaves similarly. Even the herring (*Clupea harengus*), which is confined to the sea, behaves similarly in tidal currents which "wax and wane" like freshets in streams. With strong flow, these fish are carried from shallow places, where the current is very rapid, to deeper places where it is slow, and, with diminishing tidal flow, they swim back upstream.

One hesitates to place any limits to the generality of the phenomenon until forms are considered that quite fail to resist being displaced. The essence of the behaviour is the movement of the organism to hold place in reference to a solid substratum when the circumambient medium tends to carry it away. Once the organism has been stimulated it is merely a matter of the relative strengths of the movements of organism and medium, as to whether the former holds its place, is carried away from it by the current, or goes upstream from the place.

Basis of Effect

The behaviour of an organism in heading upstream in a current, which may permit it to hold place, is called current reaction or rheotaxis. It is strongly developed in many fishes and has been found to have a complex physiological basis (Dykgraaf, 1933). In these forms, the sense organs of the lateral line seem to play a part in this behaviour. They are evidently affected by the fine turbulences in the water that are set up at the bottom and that diminish as the water works up from the bottom in its passage downstream. However, fresh-

ets clearly stimulate fish through sight and contact with bottom.

Both salmon and trout, as is well known, may become related to particular local environments, which may be called their homes. Such relation may involve a place or places for rest on the bottom, for stationing in the current, and for cover, with more or less roaming as well as precise dashes in taking food. I have frequently observed salmon, both young and old, as well as trout, occupying "homes" for varying lengths of time, both as feeding stations and as places providing cover. A freshet may greatly alter the home, even making it unrecognizable or untenable. It is to be expected, therefore, that freshets will effect a redistribution of the population and initiate migration, whether up or down. Whether or not migration is so initiated will depend not only upon changes in the condition of the fish, including its size, but also upon the character of the environment as well as the extent to which it may be altered. Brook trout, whose specific name *fontinalis* signifies relation to springs, may move very little in a cold, spring-fed brook that itself changes very little either in temperature or volume, and thus may well remain there throughout their lives from hatching to spawning. In contrast, a salmon, which is spawned in clear gravel beds of freshet-swept streams, and grows rapidly in the warm water from land drainage, is very prone to wander as a result of both its own changes and the changes in its environment, which tend to be very great.

Conclusion

Freshets effect migration of fish in three ways: (1) they stimulate the fish to ascend streams; (2) they carry fish down streams; (3) they tend to break up the "homes" to which the fish come to be related.

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THE MOLTING WITHOUT GROWTH OF SPINY LOBSTERS, *PANULIRUS ARGUS,* KEPT IN A LIVE CAR[1]

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ABSTRACT

A group of spiny lobsters, *Panulirus argus,* was kept in a live car to test a tagging technique. Records, kept on 10 that molted, show little or no increment in weight or length. There is evidence to rule out the tagging method, which is described, as the cause for inhibited growth; on the other hand, the effects of captivity conditions are considered important. The validity of current concepts of growth rate in this species is questionable since, in general, these are derived from an earlier live-car study subject to essentially the same conditions as those of the present experiment.

Individual length and weight records were made at weekly intervals for a group of spiny lobsters, *Panulirus argus,* held in a live car which was moored to the sea wall at the University of Miami Marine Laboratory near Miami Beach, Florida. The car had numerous ¾-inch holes drilled through the bottom to permit circulation of bay waters. Food consisted of fresh fish scraps, chiefly heads and skeletons which were thrown into the car once or twice a week. More food was kept in the car than the lobsters would eat but the excess was removed at intervals of several days.

The arrangement was satisfactory to test tagging methods under rushed circumstances but was an unsatisfactory means of checking the rate of natural growth. There was considerable mortality and the lobsters, especially those which had been in the car a few weeks, showed little or no growth when they molted (Table 1).

It is not believed that the tags borne by the lobsters had an effect on growth. Of the three specimens without tags (Nos. 4, 6, 10, Table 1) only No. 4 increased in length and none increased in weight. The seven marked lobsters carried a flat, 2- by 6-millimeter, celluloid tag, the anterior end of which was cut into a series of barbs. Specimen No. 2 also had a double-disc or Peterson tag (see Rounsefell and Kask, 1945) in its telson. The dart tag was pushed forward at a 45° angle into the flesh between the second and third segments to one side of the mid-dorsal line so that a tab of about 3 millimeters was left protruding. These tags remained in the flesh of the lobsters through molting. As the abdomen pulled forward the dart, with its backward slant, slipped forward between the segments of the shedding carapace.

This tagging method was conveyed to us by workers on the northern lobster, *Homarus americanus,* at the Atlantic Biological Station, St.

[1]Contribution from the University of Miami Marine Laboratory.

TABLE 1.—*Records of the* Panulirus argus *that molted in the live car*

Specimen number	Sex	Period of molt	Number of of days between capture and molt	Size before molt		Change in size after molt	
				Carapace length[1] (inches)	Weight (ounces)	Change in carapace length (inches)	Change in weight (ounces)
1	Male	Between Dec. 26, 1945 and Jan. 4, 1946	Ca. 8	3⅞	....	+⅜	.... (17)[2]
2	......	Between Jan. 5 and Jan. 10, 1946	Ca. 16	3⅞	18	+⅛	.... (0)
3	Female	Jan. 30 or Jan. 31, 1946	Ca. 20	3⅞	17	None	—1 (1)
[3]4	Female	Between Jan. 31 and Feb. 4, 1946	Ca. 23	3¾	15	+⅛	None (20)
5	......	Between Jan. 31 and Feb. 4, 1946	Ca. 23	5⅝	46	None	—2 (49)
[3]6	......	Between Jan. 31 and Feb. 4, 1946	Ca. 23	3¾	15	—⅛	—2 (20)
7	Female	Feb. 4, 1946	25	4½	27	—⅛	.... (0)
8	Male	Between Jan. 31 and Feb. 8, 1946	Ca. 25	5½	45	None	—8 (2)
9	Male	Between Mar. 23 and Mar. 28, 1946	Ca. 74	3⅞	18	None	—2 (10)
[3]10	Female	Between Mar. 23 and Mar. 28, 1946	Ca. 93	3¾	16	None	—2 (10)

[1]Carapace length = length to the end of the carapace measured on a rule lying dorsally along the carapace with its anterior end directly over the apex of the crotch that is below and between the anterior spines of the carapace.

[2]The number in parenthesis is the approximate number of days after molting that the last weight and length measurements were taken.

[3]Lobsters without tags.

Andrews, New Brunswick. Others have warned that such tags do not work as well as expected when used in the field on the northern lobster. F. G. Walton Smith of the University of Miami reports in recent correspondence over 100 returns by the end of November from approximately 1,200 spiny lobsters tagged 5 and 6 months previously. These results are encouraging but as yet there has been no method of checking losses caused by the tagging.

Many crustacea are known to have molts without growth, especially in connection with spawning. It may be significant that the molts reported here took place prior to the breeding season, possibly as the result of physiological processes initiated before the specimens were captured.

These records and comments do not imply that molting without growth is normal for the spiny lobster, but the data indicate that it can happen. In the absence of more complete information there has been a tendency to rely on the Crawford and De Smidt (1923) study for a concept of the growth rate of this species. These workers obtained their records from live-car specimens kept under better conditions than those of the present study but subject to the same kind of limitations in diet, water circulation, water quality, and space. Therefore it is erroneous to rely upon currently available information on the growth rate of this species.

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STREAM IMPROVEMENTS IN MICHIGAN

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Abstract

When war-time curtailments of labor and material forced a retrenchment in Michigan's stream-improvement program, greater attention was given to design and testing of new materials and methods applicable to specific improvement problems. In a uniform-bottomed artificial drain, fishing was improved by installation of 2-foot-square concrete blocks, cast at the site at a cost of $2.50 per block. In 5 years, there has been no maintenance cost. In a sand- and rubble-bottomed stream, deflectors were installed made of Wakefield sheet piling jetted in with a portable pump, and so designed as to escape damage from trash, floating ice, or flooding. The cost was $23.05 per unit, and no maintenance has been required after 1 year of operation. High, eroding, sand banks are being protected by planting vegetation and by construction of short wing jetties of Wakefield sheet piling. New fishing areas have been created by restoring flow through old oxbows and bayous by the use of diversion dams, and by creation of small ponds on minor spring-fed streams. For 200 earth-filled log crib deflectors, original cost was $17.45 per structure and maintenance cost over a 4-year period was $1.38 per structure per year. Experiments are under way to determine the feasibility of lowering stream temperatures by diverting dam overflows directly into the ground water table.

Introduction

In Michigan during the war-time shortage of materials and labor, a considerable portion of available facilities was expended on development of stream-improvement methods believed to be new, or at least significant modifications of existing methods, and on closer analysis of individual stream problems. Far too much stream-improvement work has been done with little or no attempt to adapt or develop techniques for specific results. Although pools and riffles are generally the most needed physical features for trout-stream improvement, a heavily sanded channel needs different treatment than a rubble- or rock-bottomed stream. The following things are most often lacking in trout streams: (1) pools and riffles; (2) bank-erosion control; (3) temperature control; (4) prevention or control of sedimentation; (5) flood control; (6) uniformity of flow; (7) pollution control; (8) fish food; (9) shade and cover; and (10) spawning facilities. This report will discuss techniques developed to meet some of these deficiencies.

Pool and Shelter Development

Lack of cover and rest areas for trout on a drainage ditch in southwestern Michigan was one problem encountered. This stream had temperatures sufficiently low to support trout but contained few pools

and little shelter. To provide these features and overcome the difficulty of holding structures in place, 2-foot-square cement blocks were placed on the bottom in staggered rows (Fig. 1). Each block weighed approximately 1,150 pounds and was cast at the site in re-usable wooden forms (Figure 2). An iron ring was embedded in one face of each block to facilitate handling. A gin pole with an extended arm was used for placement. In this particular water the conventional type of double-wing deflector with a center unit placed midway between the two wings has been most effective because it has increased the area of backwater and the amount of cover. Since the water was 2 to 4 feet deep, all but one of the structures required a second layer of blocks superimposed upon the foundation layer. Over a 5-year period there has been a gradual settling which was most rapid during the first few days after installation. Now it is planned to lift the blocks and readjust them at a higher elevation. The placement of of these structures in the stream has resulted in concentration of the fishing at the devices and, according to the anglers, an improvement in catch. An average of 64 blocks was used for each deflector, and a total of 512 blocks was cast and placed at a cost of $1,312.65. This sum included form lumber and experimentation on the best method of handling. The cost of $2.50 per block can be reduced substantially on subsequent projects. To date there has been no maintenance cost.

At Hunt Creek, where the Michigan Department of Conservation maintains a research laboratory, two sections of the creek have been improved on an experimental basis. One section was improved in 1943 by installing conventional single- and double-wing deflectors constructed of earth-filled log cribs with sodded tops (Fig. 3). These structures have functioned well but have required annual maintenance to keep them at maximum efficiency. Periodically, high water has overridden them and caused some washing. Sod and soil thus removed has had to be replaced, but to a lesser extent each year as the vegetation has become more firmly rooted. The other section was improved in the fall of 1945 by using single- and double-wing deflectors constructed of sheet piling. Ten of the 13 structures were constructed with triple Wakefield sheeting built of salvaged 1- by 10-inch pine lumber. Three boards are required for a single piling. The center one is placed between two parallel outer planks so that a 2-inch tongue and groove are formed on opposite edges. The three planks are then fastened together with nails sufficiently long to permit clinching. One end is then cut off at a 45° angle with the point on the tongue side. Individual pilings for this particular section were cut 5 feet long and jetted in by means of a portable high-pressure pump. A guide and support was installed by jetting in 8-foot cedar posts at approximately 5-foot intervals. A log stringer was placed on the upstream side of the posts. This member was squared on its upstream face, and notched and spiked at its junction with the posts. Posts and stringers were set far enough below the water surface so that they

would be continually submerged. Sheet piling was then started at the end toward the center of the stream. The first pile, which had been sharpened symmetrically, was driven with great care to keep it vertical and then was spiked to the stringer as a guide for subsequent piling. The tongue of each pile fitted into the groove of the previous one, and the 45° angle point tended to wedge them all tightly together to form a watertight seal. At its outer end the top of the structure was cut off at the water line and gradually tapered upward until at the bank line it was 4 inches above the water. The cut was made low to permit flood water to override the device and so give pressure relief and clearance for any floating trash that otherwise might collect on the structure. The deflector was built well into the bank to reduce the possibility of cut-around. Additional submerged planks or logs to act as cross-current diggers were placed slightly downstream from the end of the wing and spiked to posts jetted in to a depth of 7 feet (Fig. 4 and 5). Others were placed as a submerged downstream extension to the wing parallel with the current. Between the wings of several structures a plank or log was placed below the low-water level and parallel with the current. This particular construction has proved most efficient. After being in place a year the structure required no maintenance and none is anticipated for some time to come. The other three structures in the second improved section were built similarly except that 2- by 6-inch matched sheeting was substituted for the triple Wakefield sheeting. Matched sheeting reduced by two-thirds the amount of lumber necessary per structure, and appeared to function equally well. Deep holes have been cut below most of the structures and after 1 year those with the additional submerged construction at the midstream end of the wings have cut the deeper holes.

The 13 structures cost $306.00, or $23.54 per unit. Ten of the structures were of salvaged material which has not been evaluated in the above figure. Had new lumber at the rate of $85.00 per 1,000 board feet been used throughout, the cost would have been approximately doubled. Posts and stringers were cut from adjacent wood lots and represent only labor costs. The particular advantages of this type of construction are water-tight seals, long life, the ability under flood conditions to pass floating trash and ice, and the relief of flood pressure by overtopping. Such overtopping has little or no detrimental effect on the device. This structure has proven very satisfactory where heavily sanded conditions are encountered.

Control of Bank Erosion

A number of streams in Michigan, particularly in the northern zone, have become badly sanded by bank erosion. Attempts to control this condition are being made on portions of the Pere Marquette in the Lower Peninsula and the East Branch of the Two Hearted River in the Upper Peninsula. Considerable work was done in the 1930's by

FIGURE 1.—Arrangement of cement blocks in the Dowagiac River.

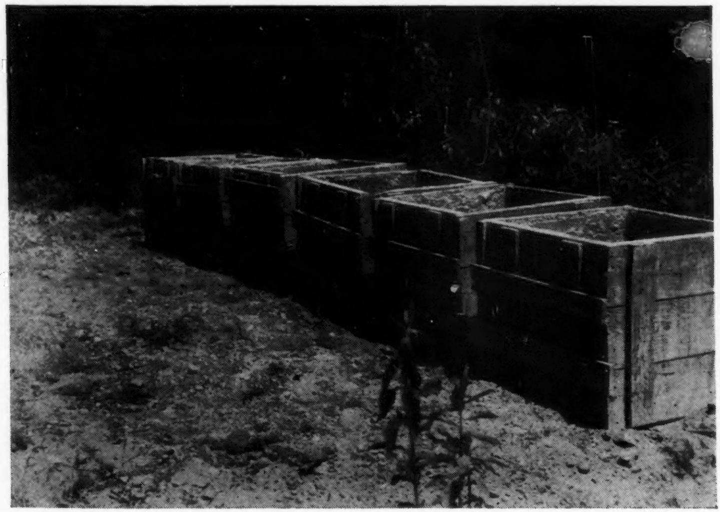

FIGURE 2.—Re-usable wooden forms for casting cement blocks.

FIGURE 3.—Earth-filled log-crib wing deflectors in the experimental section of Hunt Creek.

FIGURE 4.—A double-wing, sheet piling deflector in Hunt Creek.

the Civilian Conservation Corps on several of the worst stretches in the Pere Marquette River. This work included terracing, tree planting, and the protection of the water line by log booms. Much of the work failed, especially at the water line. It was believed that some of the old construction could be salvaged by installing a series of short wing jetties to deflect the current from the raw bank. A protective cover could then be reestablished naturally with some help in the form of grassing or tree and shrub planting. To carry out this plan jetties were constructed like the wing deflectors at Hunt Creek described above, with the exception that the terminal ends extend about a foot above low water line. They maintain this height to within about 6 feet of the bank, and then angle upward until at the bank end they are 3 to 6 feet above low water (Fig. 6). All of the wood parts extending above the water line are creosoted. The terminal ends are braced to the bank downstream with a submerged log held in place by posts jetted in, to a depth of 12 feet. It is necessary to construct two or more of these wings in series at each of the major bends where erosion is taking place. The angle at which the jetties are placed varies from approximately 30° to 45° and depends in general on the way the main current strikes the bank. Cost figures on this work are not yet available, since construction is still in progress. However, they will approximate figures given for Hunt Creek plus the additional cost of longer sheet piling and driving to a greater depth.

Creation of Additional Fishing Water

A simple method of providing more fishing is to create new water. This plan has been tried on the Little Manistee River in Michigan by the construction of a diversion dam which directs the water through an old oxbow and adds 1,700 feet of new trout water. To divert the water it was necessary to build a dam that would provide a head of not less than 2 feet. This dam was constructed of two rows of triple Wakefield sheeting 6 feet apart, braced by 4- by 6-inch oak waler and tied together by ¾-inch steel rods. The space between the sheet piling was filled with earth and the top seeded to grass and rye (Fig. 7). Additional earth, for added strength, was placed on the downstream side, completely covering the sheet piling and providing 2 feet more freeboard. The slope was sodded to the water line and the approaches grassed and planted to jack pine. Most of the heavy deposit of silt and muck which accumulated during the many years since the oxbow had been cut off from the main stream, was flushed out in the first 2 days of operation. During the construction of the dam a box-type spillway was used to prevent formation of appreciable head. After completion of the dam the spillway was filled with earth to strengthen the structure. The dam has an overall length of 110 feet and extends well into the banks at each end. Its total cost was $1,538.07.

The success of trout planting in several old rearing ponds in southern Michigan stimulated interest in developing similar ponds on waters formerly considered too small to warrant much attention. In the autumn of 1945 a dam was constructed in the Waterloo State Park Area on a stream whose flow was approximately 120 gallons per minute. This dam forms a pond of about 2 acres which was stocked with legal-sized trout in the winter of 1945-1946 and enjoyed considerable public use during the summer of 1946. Two additional ponds will be constructed during the fall of 1946, one of 6½ acres, the other of 5 acres. The possibilities of expanding this program are great and will provide trout fishing in a section of the state most deficient in this type of sport.

Temperature Reduction by Channel and Bank Development

The Clam River whose source is Lakes Mitchell and Cadillac near the city of Cadillac lies in the north-central part of the Lower Peninsula and flows southeastward into the Muskegon River. It is considered marginal for trout because relatively high water temperatures may occur during warm weather. There are at least two causes for this condition. One is the warm water from the source lakes, and the other is the widening and the shoaling of a considerable portion of the stream. Seepage runs conducted with the cooperation of the U. S. Geological Survey in the summer of 1946 during a period when no water was spilling over the dam from Lake Mitchell into the river indicated a pick-up of 22 second-feet of water between the source and a point approximately 20 miles downstream. Most of the time this large volume of spring and seepage water maintains a stream temperature sufficiently low to support trout. Because conditions in the stream are marginal, it was considered desirable to attempt temperature reduction by narrowing the channel and planting the banks. With the cooperation of the Cadillac Rod and Gun Club easements permitting public access and the right to construct and maintain improvements were obtained along the greater portion of the 20-mile stretch. To date 200 devices, mostly single-wing deflectors, have been installed. Narrowing the channel has been accomplished by placing the structures so that bars could form behind them (Fig. 8). In the 5-year period since the first deflectors were installed, portions of the stream have been narrowed by two-thirds of their former width. By careful maintenance and the addition of auxiliary devices where needed, it has been possible in some instances to extend the bar formation from one structure to the next. All but 12 of the structures were made of materials taken from the adjacent stream banks and consist of earth-filled log cribs with sodded tops. The terminal ends of 20 wings have been protected against cutting by 6 to 8 feet of sheet piling and in many cases the banks opposite the single wing deflectors have been protected either by boom logs or sheet piling. Treeless banks have

FIGURE 5.—Single-wing deflector of triple Wakefield sheeting with submerged log tailing downstream from the end of the wing (Hunt Creek).

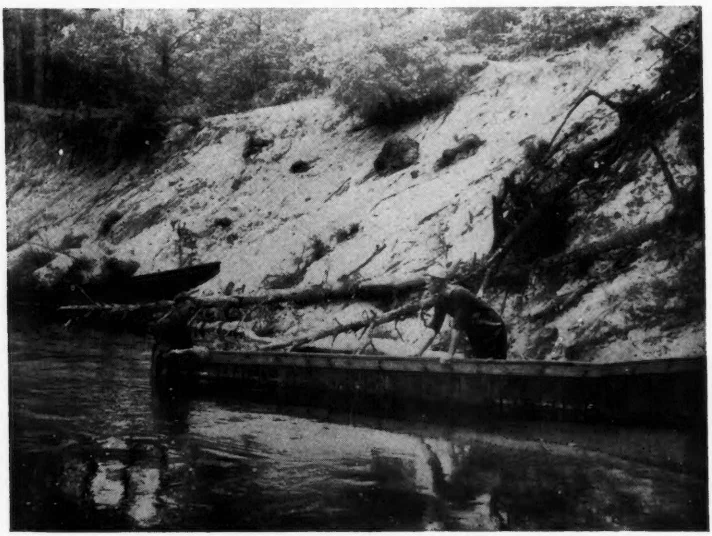

FIGURE 6.—Two wing-jetties in the Pere Marquette River designed to prevent bank erosion. Note the height differential between the stream and bank ends.

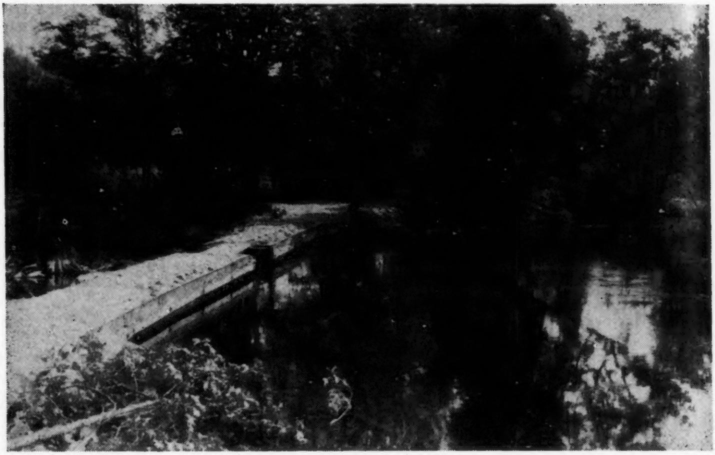

FIGURE 7.—Diversion dam on the Little Manistee River.

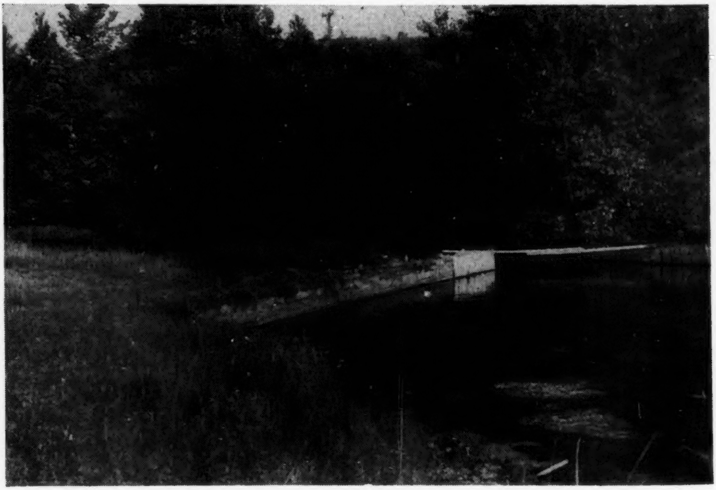

FIGURE 8.—Single-wing deflector in the Clam River with the terminal end protected by sheet piling. Note the formation of bar behind the wing.

been planted with white cedar, spruce, pine, and mixed hardwoods. The total cost of these 200 structures has been \$3,490.00 or \$17.45 each. Their maintenance for the 4-year period cost \$1,092.00 or \$1.30 per structure each year.

Increase of Ground-water Flow

In addition to the control of temperature by narrowing the stream channel and planting the banks, data are being obtained on the feasibility of augmenting spring flow. This objective would be attained by introducing all or a portion of the stream flow near the source of the Clam River directly into the ground-water reservoir which it is believed feeds the springs that now contribute most of the cold water to the stream. It is presumed that the greater volume of spring flow would reduce the water temperature materially in the warm summer months. Introduction of surface water into the ground-water reservoir would be accomplished by installation of a low-head dam to divert a portion of the flow through distribution ditches, or to flood an area large enough to absorb the diverted water. The stream flows through a large glacial outwash plain of highly pervious sand and gravel of considerable depth.

In March 1945, 14 test wells were jetted 2 to 5 feet below the level of the ground-water table in the area that may be flooded. The water level in these wells was checked at bi-monthly intervals up to June 1, 1946. Since June 1 weekly checks have been made and will be continued for an indefinite period. These data indicate fluctuations in the level of the ground-water table, and to a degree, the speed of percolation through the aquifer. Variations in the water level between wells indicated the ground-water gradient, and the direction of flow of subsurface waters. The level of the ground-water table in the test area has remained consistently below the level of the stream, with the difference increasing in proportion to the distance of the well from the stream. These data show a flow from the stream to the underground waters and also the ability of the ground-water reservoir to absorb additional waters. An effluent flow is indicated further by the above-mentioned seepage runs wherein the section under discussion lost one second-foot of water in a distance of 1½ miles. Three miles below the site of the proposed spreading operation is the first tributary. This spring-fed stream is believed to be the first outcropping, other than the Clam River itself, of the water table that would be augmented by the spreading operation. If the foregoing assumptions are correct, a rather simple method of temperature reduction for many streams of similar character has been found. So far as the author can determine, the proposed plan will be the first application of this principle to improve trout streams by temperature reduction.

The principle of recharging ground-water reservoirs is not new. It has been used for many years in California and other western states

for irrigation purposes. Many places in the eastern states of Ohio, New Jersey, New York, West Virginia and others are using this method to maintain underground reservoirs for cooling water in air conditioning plants, and for industrial areas where heavy pumping has depleted the ground-water supply. Meinzer (1946) stated that "The plan involves recharging the water from the public supply in winter when the surface water is cold, thus increasing the supply of cool ground water in summer when the surface water is too warm to be satisfactory for cooling purposes." The success of artificial recharging has been demonstrated many times both in Europe and the United States and its application to the improvement of trout streams is merely a new use for a proven method.

The high internal friction of even the most permeable aquifers assures a considerable time lag between recharging operation and discharge through seepage and spring flow into the stream. This time lag is determined by the distance through which the ground water percolates, porosity and permeability of the aquifer, and the ground-water gradient. Time lag is of great value from a stream-improvement standpoint for generally the period of greatest recharge would be at the time of the spring break-up. The water thus stored would be released gradually at low temperature during the critical period in July and August.

A recording thermograph was placed 4 miles downstream from the site of the projected spreading operation and has been running continuously since June 3, 1946. The maximum water temperature recorded in the summer of 1946 was 81° F. on July 19; it remained at that figure for a 3-hour period. The air temperature on that day remained above 88° F. for 5 hours and reached a maximum of 91° F. Comparisons will be made between the average air and water temperatures for a considerable period both before and after the spreading operation. In cooperation with the U. S. Geological Survey a stream gage was installed near the site of the thermograph and 5-day-a-week recordings indicating the volume of flow have been made since June 3, 1946.

All data collected since 1945 will be analyzed and the resulting conclusions will determine the nature of the spreading operation and the time of its initiation.

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TURBIDITY AS A FACTOR IN THE DECLINE OF GREAT LAKES FISHES WITH SPECIAL REFERENCE TO LAKE ERIE[1]

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Contents

Abstract

Fish live and thrive in water with turbidities that range above 400 p.p.m. and average 200 p.p.m. The waters of the Great Lakes usually are clear except in Lake Erie where the turbidities of the inshore areas averaged 37 p.p.m.; the turbidities of the offshore waters averaged less. Lake Erie waters were no clearer 50 years ago than they are now. In fact, the turbidity values are less now than they were in the earlier years; the annual average of the inshore waters dropped from 44 p.p.m. before 1930 to 32 p.p.m. in 1930 and later, and the April-May values decreased from 72 p.p.m. to 46 p.p.m. Any general decline in the Lake Erie fishes cannot be attributed to increased turbidities. Furthermore, these turbidities averaged well below 100 p.p.m. and, therefore, were too low to affect fishes adversely.

Turbidity in the open waters of Lake Erie is primarily the result of wave action induced by winds. River discharge is a minor factor even in the western end of the lake. Other probable factors are plankton, the eastward movement of the water mass, currents, seiches, and possibly bacteria. Wave action is undoubtedly the dominant agency in soil erosion along the shores of all of the Great Lakes.

No evidence exists that fluctuations in the abundance of zooplankton, the basic food of fishes, and of the fishes themselves are positively correlated in Lake Erie or that the plankton crop in this lake is ever in short supply. On the contrary, all available evidence shows that Lake Erie is comparatively rich in plankton and that the western end in spite of its turbidity is richer than the eastern. Some factor other than turbidity dominates the basic productivity of western Lake Erie.

With respect to turbidity Lake Erie has not become less suitable for fishes. This conclusion also receives support from the study of the fishes themselves. It was demonstrated that the growth of the western Lake Erie fishes compared very favorably with that of fishes in the other Great Lakes or similar waters.

[1]Presented by title at the seventy-sixth annual meeting.

It was shown further that the known occurrence of relatively strong year classes in this lake was not consistently associated with low turbidities and conversely that the known low turbidities of the Lake Erie waters were not always accompanied by large year classes. Also, contrary to the "turbidity theory," certain clean-water varieties, such as the walleye, have increased tremendously in recent years in Lake Erie, whereas the supposedly turbid-water forms, such as the sauger, have decreased in abundance. Reference was made to Doan's work, wherein he attempted to show correlation between turbidity and abundance for several species of Lake Erie fish but failed to do so except for the sauger where he reported a positive correlation. With respect to the productivity of fishes Lake Erie ranks first among the Great Lakes, and the western end in spite of its greater turbidity surpasses the eastern. As judged by certain accepted standards of water suitability, Lake Erie ranks high, and the western end again surpasses the eastern. Finally, it was pointed out that fishes which inhabit the clear waters of the Great Lakes declined as well as those which live in the more turbid waters and that turbidity, therefore, cannot be a factor in the depletion of all Great Lakes fishes. Furthermore, the reduction in abundance repeatedly has been associated with increased fishing intensity.

All of the evidence indicates, then, that soil erosion on farms and the turbidity of the water were not major factors, if operative at all, in the decline of Great Lakes fishes and that they did not make Lake Erie unsuitable for fish life.

Introduction

Programs for the control of soil erosion have been designed primarily to aid agriculture; secondarily to prevent or control floods and to protect ground water for use by industries and municipalities. The improvement of fish habitats, particularly in streams, is merely a by-product of these programs. I believe in soil conservation. No rational person can conscientiously oppose it. However, with respect to the fisheries I feel that the program has been oversold—at least in some localities. This certainly is true where, for example, soil erosion on farms is held responsible for the decline of the fisheries in the Great Lakes (Langlois, 1941).

It is the view of Langlois that turbidity is the major factor in the abundance of Great Lakes fishes, especially in Lake Erie. He holds further that silt, clay, and other suspensoids carried into Lake Erie by tributary streams determine the extent of turbidity; that with the expansion of agriculture the quantities of stream-borne materials have increased notably; that turbidity values have risen greatly, making Lake Erie an unsuitable habitat for such first-choice species as the cisco or lake herring (*Leucichthys artedi*), whitefish (*Coregonus clupeaformis*), yellow perch (*Perca flavescens*), and walleye (*Stizostedion vitreum vitreum*); that improper land-use practices and not destructive fishing and inadequate regulations are therefore responsible for the decline of the fisheries. The main points of his thesis are fairly well outlined in the following scattered quotations from his 1941 paper: "The specific factor that may be held responsible for

changing Lake Erie from a suitable place for the cisco, whitefish, and perch is the increased turbidity of the waters in the western part of the lake. . . . . The average of 40 parts per million of suspended matter in the water there has been found to change quickly to more than 200 parts per million with a strong wind. . . . . This same factor of turbidity is doubtless mainly responsible for the elimination of the vegetational areas that are so essential to perch and other fishes. . . . silt pollution has become a major factor in all of western Lake Erie. . . . . The silt loads carried into the bay and the lake by the Maumee River during many springs . . . may well account for the failure of other year-classes [of walleyes] to become abundant and make continuously good fishing for that species. . . . . Silt has also been carried into the lake and deposited over the hard bottoms around the islands. Hence the fish species which require clean hard bottom for the successful incubation of their eggs, including the ciscoes and whitefishes, have been greatly reduced in abundance and appear to be approaching extinction. . . . . Those which need vegetational areas for spawning and early growth, as the yellow perch, are also showing diminishing numbers. . . . . Those which tolerate turbid water, as the sauger, sheepshead, catfishes, and carp are thriving under present conditions and in no danger of depletion. . . . these species have increased in the catch as they have increased in abundance and less hardy species have declined. . . . . It now appears that the main problem of maintaining the commercial fisheries industry of Lake Erie may be one of land use and closely associated with the erosion problems of farmers, conservationists, and industrialists. . . . . The improvement of the habitat by reduction in turbidity is the indicated plan of action if the first choice species, whitefishes, cisco, and perch, are ever to be restored in abundance.'' Unfortunately the author presented no supporting data for these and many other questionable statements in his 1941 paper.

The Langlois turbidity theory, if true, would carry with it the most sweeping implications. Specifically, it would mean that all efforts at the rehabilitation and conservation of our declining Great Lakes fisheries through the improved control of the intensity, time, and methods of fishing or by other management procedures are foredoomed to failure and might as well be abandoned.

However, this theory is not acceptable; it can be invalidated easily on any one of several counts. To act on it, or rather to fail to act because of it, could but end in disaster for the fisheries. Even now, no inconsiderable harm has come from the wide publicity given Langlois' beliefs. Not only has attention been diverted from the really vital problem of destructive fishing and the need for its correction, but commercial fishermen have been encouraged to assume the attitude that the dwindling stocks of fish may properly be exploited without any thought of conservation.

Thus it is that my life-long interest in and deep regard for the welfare of the Great Lakes fisheries forbid my continued silence. I propose, therefore, in this paper to undertake a thorough examination of the question of the relationship between turbidity and the abundance of fish. In the course of my discussion I expect to demonstrate beyond all doubt that the "turbidity theory," superficially plausible as it may seem to be, breaks down completely in the face of the facts —that the future prosperity of the Great Lakes fisheries depends, not on scientific farming, but rather on scientific fishery management.

Although, as stated above, Langlois' turbidity theory can be proven invalid on any of several counts, I shall nevertheless consider each of the important points. I feel that a thorough discussion of the entire subject in a single paper is desirable, since involvement in an extended controversy would serve the interests neither of science nor conservation. The treatment will include: a survey of available information on the reactions of fish to turbidities of varying intensities; a presentation of figures on turbidities in the Great Lakes with special reference to long-term trends in Lake Erie; a discussion of factors of turbidity; an appraisal of Lake Erie as a habitat for fish as indicated by plankton productivity and by the growth and production of fish; a reference to depletion in the clear and in the turbid waters of the Great Lakes; and a demonstration that annual fluctuations in turbidity exhibit no clear-cut relationship to the strength of year classes. Much of the discussion will be based on information drawn from the literature. Here, citations will be limited largely to those papers that contain quantitative data.

Review of Literature on Effects of Turbidity on Fish

Stream populations of fish in areas subject to soil erosion.—The harmful effects of soil erosion and the resulting siltation and increase of turbidity should be most apparent in stream populations, since those fish are exposed much more directly to the changes that accompany agricultural development than are the inhabitants of lakes. Yet the observations on two small streams in which the abundance and species composition of fish were investigated at widely separated intervals of time suggest that even in that seemingly vulnerable habitat fish exhibit a remarkable tolerance to altered conditions.

In 1897 E. B. Williamson and R. C. Osburn identified 35 species of fish from Blacklick Creek, a small, 30-mile stream in Franklin County near Columbus, Ohio. Forty-five years later in 1942 E. L. Wickliff (1945) collected 55 species from this same stream—the 35 varieties recorded in 1897 plus 20 additional forms. At one place in the creek Williamson and Osburn collected 17 species; 23 years later, in 1920, Wickliff and L. F. Edwards took 18 species at that spot including the 17 reported in 1897; and in 1943 all of the 18 species were still there! Wickliff concluded that ". . . the total kinds of fishes are not decreas-

ing in Blacklick Creek. The fact that this creek has dry riffles, low or dry pools in the upper section for part of the year, and very low water in the middle and lower sections during the summer and early fall shows the species in the creek are able to take it. . . . . This extensive list of fishes proves the hidden possibilities of different forms to become abundant when stream conditions change.'' He also found that the growth and survival of the fishes were not affected by seasons of high turbidities, since ''. . . the almost continuous high and muddy water during April, May, June, July, and August of 1937 (the important hatching and growing months for young fish) produced a good crop of baby fish with growth rates of the species studied as favorable during the same seasons as they were for the other years studied. . . . . The rapid recovery of the fish proves that the weather and natural stream conditions, plus the presence of nine low dams, are not as detrimental as they were thought to be.''

The second illustration relates to Lost and Gordon Creeks in the Maumee drainage of northwestern Ohio. Trautman (1939) in comparing the present and past abundance of fishes in the undredged sections of these creeks found that ''. . . there has been little change in numerical abundance of the various fish species in these sections between 1887 and 1938,'' a period of 51 years, in spite of the facts that in this region the forests have been largely removed, the meadows have often been heavily grazed, and practically all have been cultivated, and the soil is readily eroded.

Extent of turbidities tolerated by fish in nature.—The two studies just described demonstrate clearly the unsoundness of any sweeping generalizations that are based purely on the assumption that agricultural development with its concomitant soil erosion must of necessity be detrimental to the fish populations of a stream. The mere presence or absence of turbidity is no criterion of the productivity of a stream or lake as measured in terms of fish yield, for as Ward (1938) wrote, ''Fish live and thrive in rivers carrying large loads of silt. One could make a long list of such streams in the central West and on the slopes of the mountains between that region and the Pacific coast. To be sure, all of these do not have salmon runs, but they do carry trout . . .'' (p. 22). Ellis (1937) and his staff, for example, made 514 turbidity determinations at 202 stations on streams in 8 large river systems, at each of which stations a good mixed fish fauna and associated organisms were thriving. Forty-one percent of these readings indicated turbid or muddy water, 59 percent clear or cloudy. Similarly, of 237 determinations at 52 stations on the Mississippi River system with a good fish fauna, 85 percent showed turbid or muddy water, 15 percent clear or cloudy, and of 260 measurements at 79 stations with a medium, poor, or no fish fauna 81 percent indicated turbid or muddy water, 19 percent clear or cloudy.

Whether or not turbidity becomes a factor in the abundance and variety of fishes is determined largely by the quantity of suspended

matter and the degree of roiliness. Unfortunately no one knows exactly at what point turbidity influences the welfare of different fishes. Ellis, Westfall, and Ellis (1946) reported that "It is not possible to set standards for minimal turbidity or loads of suspended matter tolerated by fishes as there are many factors to be considered in evaluating the detrimental action of suspended matter . . ." (p. 58). However, there are some actual findings that may be helpful in appraising the probable significance of varying degrees of turbidity.

For example, the turbidities of the Rogue River, Oregon, into which was discharged the muddy waters of placer mines, ranged from 50 to 440 and averaged 113 p.p.m. (Ward, 1938). Ward found that these waters were not inimical to the fish and fish-food supply. Swartley (1938) recorded average turbidities of 27 to 245 p.p.m. for a group of western streams, some of which are good salmon rivers. Ellis (1940), reporting on the mine-waste pollution of Bear Butte Creek, South Dakota, found that ". . . over 6 miles of a fine mountain stream have been rendered unfit for fish and the supporting fish-food organisms" (p. 8). The residual turbidity (turbidity after one hour of settling) of the water rose from less than 1 p.p.m. in the unpolluted area to 5,000 p.p.m. in the polluted. In addition, the very fine silt had high adhesive properties, and the bottom fauna and all submerged objects were covered with deposits. Ellis, Westfall, and Ellis (1946) reported that muddy glacier streams with residual turbidities of 110 A.P.H.A. units supported good trout faunae (total turbidities were of course higher). These same authors discovered that in Whitewood Creek, South Dakota, heavily polluted by mines, fishes reappeared in the stream when the residual turbidity had dropped to 720 units. Platner (1946) found the turbidities of the Mississippi River to vary with the sections. In the upper part they averaged 50 p.p.m., in the lower 300 p.p.m., and below the mouth of the Missouri River 1,880 p.p.m. He reported that the Mississippi River was not in a critical condition with respect to fish, although the upper section presented the more favorable environment, and that in comparison with waters producing an abundant fish fauna it would be rated as good.

Experiments on reactions of fish to turbidity.—Very little experimental data are available on the direct effect of turbidity on fishes. Griffin (1938) subjected fingerling fish, which usually are more sensitive to changes in environment than adults, to highly turbid waters (390 to 5,960 p.p.m. of sediment) and found that "The results of the experiments indicate that young trout and salmon are not directly injured by living for considerable periods of time in water which carries so much soil sediment that it is made extremely muddy and opaque. They also indicate that cutthroat trout and [chinook] salmon fingerlings can feed and grow apparently well in very muddy water. The sediment load of the water in these experiments was continuously much greater than it is in the ordinary muddy stream" (p. 29). Cole (1935) likewise demonstrated experimentally that fishes can move

through water heavy with suspensoids without injury. In free-swimming fish the mucus washes away any fine suspensoid particles that may lodge on the gills (Ellis, 1937).

Schneberger and Jewell (1928) attempted to learn the exact quantitative relationship between fish production in ponds (largemouth black bass, bluegill, crappies) and turbidity. They reported ". . . that a decrease in turbidity is accompanied by an increase in fish production until the turbidity has fallen to a point below 100 ppm. [average], after which the two curves operate independently. In other words, it appears that the higher turbidities are sufficient to prevent fish from developing, but in moderate or low turbidities the number of fish is controlled by other factors" (p. 10).

Possible benefits from turbidity.—The above review of the literature shows very clearly that although no fixed standards of turbidity have been set up fishes can and do live and thrive in muddy waters and that average turbidities well over 100 p.p.m. and probably as high as 200 p.p.m. or more appear to be harmless to fish life; extremely high turbidities and heavy siltation are, of course, detrimental. I do not recommend the conversion of clear waters to turbid waters although the presence of a certain amount of fine silt may yet prove to be highly beneficial to young fish. Ward (1938) referred to this possibility when he wrote, "It has been shown that the presence of finely divided suspensoids of natural origin may be of advantage to the microbiota which constitutes the foundation element in the food supply of water. Studies on aquatic biology conducted by the Wisconsin Survey demonstrated that colloidal organic particles collect on carbon and sand grains to build a culture medium for aquatic bacteria. . . . . Thus would be multiplied the food supply of protozoa and other types of aquatic life which subsist primarily on bacteria. Among such are young stages or larvae of small crustaceans and insects which form such an important part of the food of young fish at the start of life. It is even possible that colloidal particles encased by bacterial cultures may form an element in the direct food supply of young fish" (p. 25). Ward then went on to state that he had on many occasions found the alimentary canal of very young fish completely filled with what was apparently only mud, even though the fish were healthy and vigorous. This mud, however, might have been particles coated with zoogloea or bacterial jelly and ingested because of its nutritive value. Further, Lagler and Ricker (1942) pointed out in their report on Foots Pond, Indiana, that in spite of the muddiness of the water (no data given in p.p.m.) during most of the year ". . . natural propagation is very successful, and survival is favored by the extensive beds of spatterdock and by water turbidity" (p. 69) which offer protection from predators.

Standards of suitability.—The best and most direct method of determining the suitability of any body of water for fish is to study the fishes themselves. If a lake or stream has a good mixed fish fauna and

if survival and growth are satisfactory as determined by proper comparisons within the general region, it may be accepted that the environmental conditions are favorable to fish life. Ellis (1937) recognized this principle in part in establishing standards of water suitability for fish. These standards were determined by studying the characteristics of those ". . . waters in which a mixed fauna of freshwater fishes of the common warm water types including desirable centrarchids, cyprinids, catostomids, and silurids, as well as such tolerant forms as carp and gar, will thrive" (p. 368). He found that the values for dissolved oxygen, pH, ionizable salts, carbon dioxide, ammonia, and suspensoids of ". . . favorable waters, i.e., waters supporting good mixed fish faunae, fell within rather definite limits, and that deviations from these limits in our inland streams were almost always indicative of conditions unfavorable to aquatic life" (p. 368).

Conclusions from survey of literature.—I have thus far outlined briefly some of the results obtained and conclusions reached by several investigators concerning the effect of soil erosion and turbidity on fishes in waters other than the Great Lakes.[2] In summary they show: (1) that agricultural development with its accompanying soil erosion need not of necessity be detrimental to stream fishes; (2) that fishes, even the so-called clear-water forms, live and thrive in very muddy streams with total turbidities that may range above 400 p.p.m. and average more than 200 p.p.m.; (3) that no fixed maximum standard of turbidity tolerated by fishes can be set since the load of suspended materials in p.p.m. or percentage volume as well as other factors must also be considered; (4) that young trout and salmon are not directly injured by waters of extremely high turbidity (390-5,960 p.p.m.), and that they feed and grow well in such waters; (5) that fishes can move without injury through water heavy with suspensoids; (6) that fish production (in numbers) in ponds is not adversely affected by average turbidities under 100 p.p.m.; (7) that fine silt coated with bacterial jelly may be an important source of the basic food of fishes in turbid waters; (8) that turbidity may favor the survival of young fishes by protecting them from predators; and (9) that standards of water suitability for fish have been determined from characteristics of those waters that contained a good mixed fish fauna. These conclusions have been derived almost entirely from studies based on fishes inhabiting streams where the exposure to erosion is much greater and more direct than in lakes, especially those of such size as the Great Lakes.

Turbidity of Great Lakes Waters

With the above review of previous studies as a background, I am now prepared to discuss turbidity as a factor in the decline of fishes

[2]Many others have written on the effects of siltation on fish and other aquatic life, but none of them has to my knowledge published specific data on the quantitative relationship between turbidity and the abundance of fish.

in the Great Lakes, particularly in Lake Erie. It will be shown that judged by the standards set forth above and on the basis of other data Lake Erie and the other Great Lakes have not been made unsuitable for fishes by soil erosion.

The waters of the Great Lakes other than Lake Erie are admittedly clear except for short periods of time in the shallow inshore areas during heavy runoffs and severe wave action. Palmer (1903?) published information on the turbidity of Lake Michigan at Chicago, Illinois, for every month in the years, 1897-1900. He indicated his results in terms of "slight," "distinct," "decided," and "much" as noted from visual inspection of the sample of water on its receipt. Only in 1898 were a few turbidities recorded as "distinct"; in all other years they were almost always either "slight" or "very slight." Dole (1909) and Clarke (1924) published a series of turbidity records for the several Great Lakes, obtained monthly in 1906-1907 (not always complete). All of the turbidities were extremely low except those for Lake Erie as may be seen from the following averages of all readings in p.p.m.: Lake Superior at Sault Ste. Marie, Michigan—2; Lake Michigan at St. Ignace, Michigan—Trace; Lake Huron at Port Huron, Michigan—Trace; Lake Erie at Buffalo, New York—41 (range 2-190); Maumee River at Toledo, Ohio—143 (range 9-900); St. Lawrence River at Ogdensburg, New York—4.5.

Not many turbidity readings have been published for recent years for the Great Lakes (except Erie) but those recorded by the Michigan Stream Control Commission (1937) for Saginaw Bay, Lake Huron, for early fall (August-October 1935) and spring (April-July 1936) give us some idea of the present degree of turbidity in the open upper lakes. It should be mentioned that many streams including the Saginaw River, which with its tributaries drains an area of 6,400 square miles, discharge their waters into the Bay and that this fact together with the shallowness of the Bay tends to increase its turbidity far beyond that of the open lakes. The highest turbidities were recorded at the mouth of the Saginaw River; they had a range of 12-75 and an average of 25 p.p.m. The highest reported for the open bay was 25 (two readings), and the average was about 10, an exceedingly low value for such shallow water.

Daily (1938) recorded turbidities for the inshore waters of Lake Michigan at Evanston, Illinois. Part of his water samples was taken from the Evanston Water Filtration Plant and the remainder directly from the lake at the end of the breakwater some 213 feet from shore. His monthly averages (as read from his curve) ranged from about 5 to 39 p.p.m. with nearly all of the averages running below 25 p.p.m. His weekly averages varied from about 3 to 98 p.p.m. with most of the figures falling below 20 p.p.m. Damann (1943), who studied the turbidity records collected by the water department of Chicago, reported that "Turbidity, or at least the turbidity as measured at Chicago at a depth of 15 to 30 feet, had little or no relation to plank-

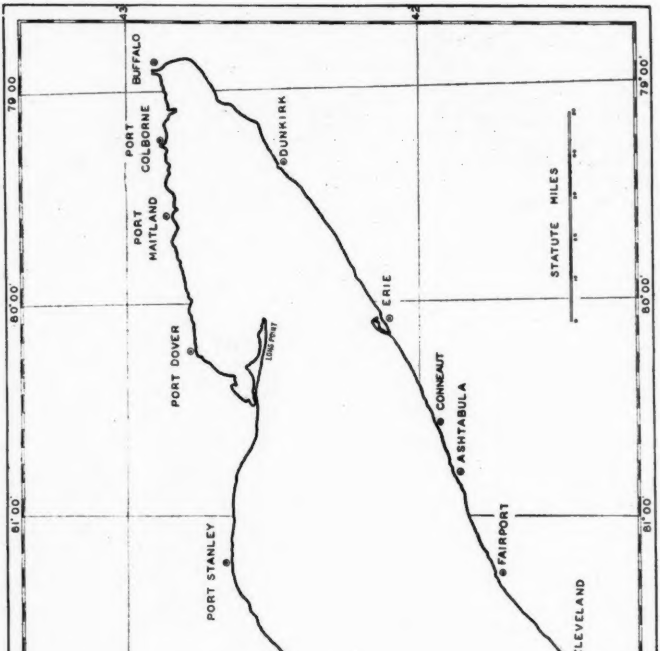

FIGURE 1.—Map of Lake Erie.

ton production or periodicity" (p. 228) in southern Lake Michigan.

It seems safe to conclude from the above information on turbidity and the review of the literature (p. 288) that the roiliness of the waters of the Great Lakes other than Lake Erie does not appear to be sufficiently great to affect adversely the welfare of fishes.

Lake Erie turbidities average higher than those of the other Great Lakes. However, records show that contrary to Langlois' theory the Lake Erie turbidities have not increased in recent years. Erosion, siltation, and turbidity are not recent developments in Lake Erie. These processes began thousands of years ago as soon as Lake Erie was formed and the waves and other agencies started their attack on the shore line and the surrounding land area; they existed at the time when the first commercial fishing gear was placed in the lake (about 1815), as well as through all the later years when fish were plentiful in the lake. Published reports referred repeatedly to the unusually muddy waters of Lake Erie and its tributaries in the 1870's and later years. For example, Dr. E. Sterling (1876) of Cleveland, Ohio, wrote on February 4, 1876, that Lake Erie water was unusually muddy but that it did not ". . . interfere with the perfect development of the White Fish egg. . . . ."

Scientific records of turbidities of Lake Erie water at or near water intakes or of the Lake Erie tributaries have been obtained by the Ohio State Board of Health as early as 1898. The thirteenth Annual Report of this Board (1899) stated that "The water of this stream [Sandusky River], in 60 per cent of the samples taken, gave a prominent turbidity mostly due to the suspended clay in a finely divided state. Clay is found quite abundantly along the course of the river" (p. 409). Again, "The turbidity of the Maumee [River] is similar to and slightly greater than that of the Sandusky [River]" (p. 417). Further, "Besides the danger from sewage pollution, the [Sandusky] bay water is objectionable on account of its muddiness after every storm. As the average depth of the Sandusky bay is only seven or eight feet, every high wind stirs up the bottom completely and makes the water very muddy" (p. 448).

The sixteenth Annual Report (1902) provided a few daily turbidity records for the lake for the period, April 24-October 24, 1901. At Conneaut (see Fig. 1) turbidity was very slight (trace) but at Painesville (Fairport) the average of five readings was 112 p.p.m. (range 58-178) and at Port Clinton the average of three determinations was 364 p.p.m. (range 78-923).

A special report (Burgess, 1908) on an investigation of water and sewage purification plants in Ohio for the years, 1906-1907, gave considerable more information on Lake Erie turbidities. The ten readings at Conneaut in June, September, and December 1906 averaged 25 p.p.m. (range 10-70), and the seven recordings for April 2 and 3, 1907, averaged 79 (range 60-110). Monthly averages for the period, June-November 1907, which were based on daily readings varied from 15

FIGURE 1.—Map of Lake Erie.

to 94 and averaged 38 p.p.m. The report stated that "During the winter of 1906-07 the lake water was unusually turbid, and in fact, at no time during this season was its turbidity less than 50 parts per million. The maximum turbidity during this period was probably about 200 parts per million. . . . During periods of high northerly winds the lake water is turbid . . . during the spring months . . . the turbidity . . . is frequently as great as 200 parts per million" (pp. 87, 88).

At the Elyria intake (less than 2 miles west of Lorain) the following turbidities were recorded in p.p.m.: nine readings on August 15-17, 1906, averaged 39 (range 30-50); seven readings on October 28-29, 1906, averaged 206 (range 110-470); seven readings on February 5-6, 1907, averaged 30 (lake covered with ice); and nine readings on June 8-10, 1907, averaged 67 (range 35-100). Monthly averages based on daily readings for the period, October 1906-June 1907, varied from 75 to 286 p.p.m. and averaged 160. The report stated that "Considerable variation is noted in the turbidity of the water at the [Elyria] intake and occasionally it is very dirty, due to the action of heavy seas which tend to stir up the deposited silt from the bottom of the lake" (p. 115).

At the Linwood Park intake a turbidity of 20 p.p.m. was recorded on August 12, 1907.

Monthly averages based on daily observations were compiled for the turbidities of the lake water at the Lorain intake for the years 1905 and 1906 (February 1906 excluded) and for the months of January-April and October-December 1907. In 1905 these averages varied from 30 to 103 and had a mean of 52 p.p.m.; in 1906 they ranged from 43 to 194 and averaged 87 p.p.m. In 1907 the seven values averaged 135 p.p.m. (range 52-249). The report stated that in winter months the lake is much more turbid than in summer. On April 17, 1905, turbidity reached 350 p.p.m. and on December 7, 1906, it was 800 p.p.m. Twenty-three readings on June 4-6, 1907, ranged from 100 to 240 and averaged 146 p.p.m.

Daily turbidity readings were obtained also for the lake water at Vermilion. The monthly averages for the period, January-September 1907, (April excluded) varied from 40 to 288 and averaged 91 p.p.m. Special observations were made on various days: eight readings on August 15-16, 1906, averaged 52 p.p.m. (range 35-60); four determinations on October 24-25, 1906, averaged 102 p.p.m. (range 70-170); two observations on February 7, 1907, averaged 35 p.p.m. (lake covered with ice); and five records on June 11-12, 1907, averaged 70 p.p.m. (range 50-90). During the period, May 6-17, 1907, water was taken from the Vermilion River, which was extremely turbid—average turbidity 580 p.p.m.; maximum 800 p.p.m.

These data obtained from the three reports of the Ohio State Board of Health together with those recorded by Dole (see p. 289) represent all of the precise measurements of turbidity of Lake Erie that are

available to me for years preceding 1910. When compared with more recent data they indicate that Lake Erie water was no clearer 50 years ago than it is now. In fact the curves of Figures 2-5 and the data of Tables 1 and 2 show that in general turbidity has decreased. These curves and tables were based on an excellent series of unpublished records of monthly averages (computed from daily readings of turbidity) obtained from the files of the Ohio State Board of Health,

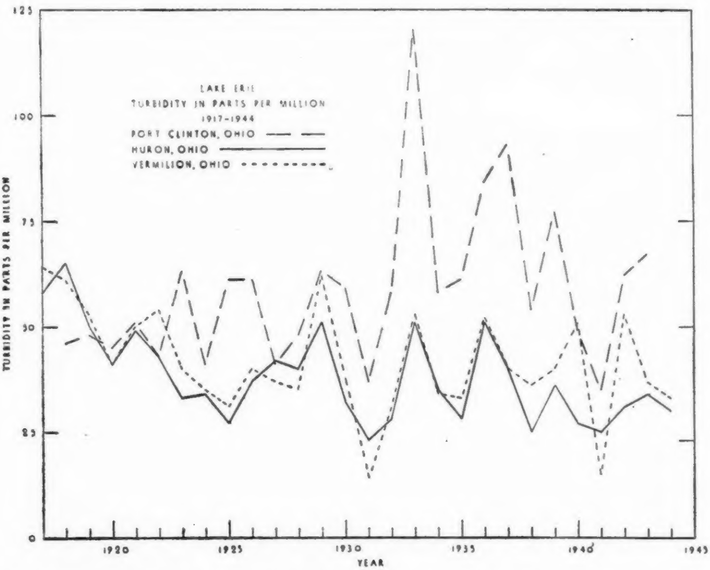

FIGURE 2.—Lake Erie annual turbidities in p.p.m., at the city water intakes of Port Clinton, Huron, and Vermilion, Ohio, 1917-1944.

Columbus, Ohio, and of similar monthly averages published in the annual reports of the Commissioners of Water Works (now called Bureau of Water, Department of Public Affairs), Erie, Pennsylvania.[3] The Figures present the yearly or April-May averages of turbidity of the lake water at various city intakes for different years during the period, 1905-1944. Table 1 shows for each locality the grand average

[3]I am deeply grateful to Mr. T. R. Lathrop, Assistant Engineer, Ohio State Board of Health, for permission to copy the Ohio records, for explanatory information given me, and for many other courtesies extended in his office. I am likewise thankful to Messrs. J. D. Johnson, General Superintendent, and T. J. Ziegler, Office Manager, Bureau of Water, Erie, Pennsylvania, for the records obtained in their office and for copies of the annual reports that were provided us.

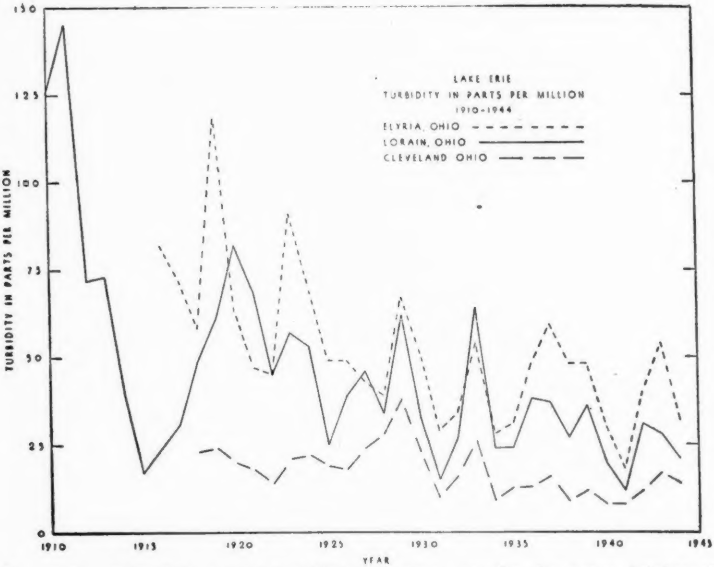

FIGURE 3.—Lake Erie annual turbidities in p.p.m., at the city water intakes of Elyria, Lorain, and Cleveland, Ohio, 1910-1944.

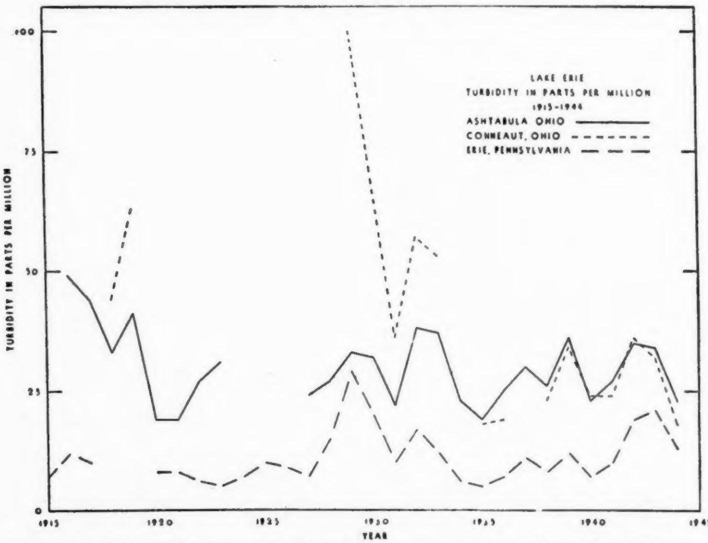

FIGURE 4.—Lake Erie annual turbidities in p.p.m., at the city water intakes of Ashtabula and Conneaut, Ohio, and Erie, Pennsylvania, 1915-1944.

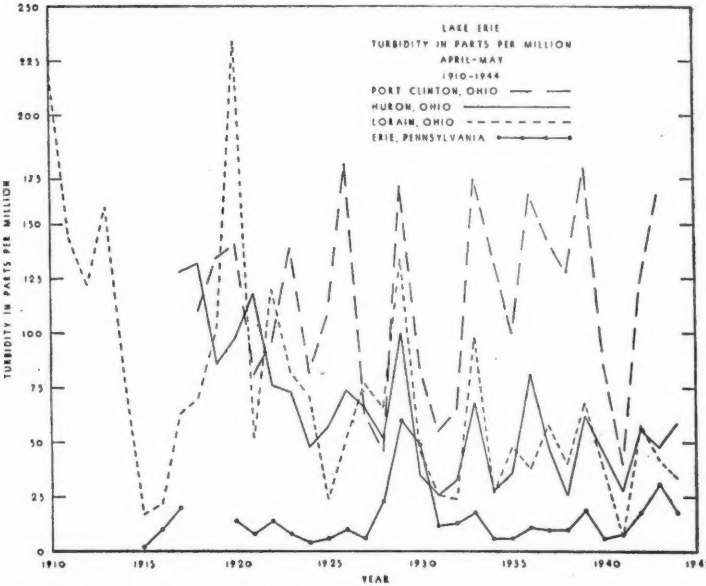

FIGURE 5.—Lake Erie turbidities in p.p.m., at the city water intakes of Port Clinton, Huron, and Lorain, Ohio, and Erie, Pennsylvania, for the months of April-May, 1910-1944.

turbidity (unweighted mean of annual averages) for each of two series of years, separated by the year 1930, and for all years combined (last column). Table 2 gives similar averages but for the months of April-May only.

All of the intakes in the lake were or are approximately ¼ mile or less offshore except those at Cleveland which are less than 4½ miles from shore and the one at Erie which is nearly a mile offshore.[4]

Because of the greater distance from shore, the zone of most intensive erosion, turbidity readings at Cleveland and Erie averaged less than those at adjacent cities. The offshore waters undoubtedly are clearer than the inshore waters but the trend of the turbidities in both regions should correspond fairly well from year to year. This assump-

[4]The new intakes at Toledo and Sandusky are about 1½ miles and 0.6 mile respectively from shore but the turbidity data for these new locations were not included in Tables 1 and 2 since they were not comparable with the data of the earlier years; the waters of the Maumee River and Sandusky Bay are more roily than those of the open lake. The annual mean turbidity at the new Toledo intake during the years, 1942-1944, was 64 p.p.m. as compared with the grand average of 133 p.p.m. for the Maumee River, and the yearly mean at the new Sandusky intake during the period, 1941-1944, was 23 p.p.m. as compared with a general average of 59 for the Bay.

TABLE 1.—*Mean turbidities (p.p.m.), based on annual averages, of raw water from intakes of Ohio and Pennsylvania water plants along Lake Erie, 1905-1944*

[All intakes are located in Lake Erie proper unless otherwise stated. See map (Fig. 1) for location of cities.]

Locality	Before 1930			1930 and later				
	Period of years	Number of years with data[1]	Mean turbidity	Period of years	Number of years with data[1]	Mean turbidity	Increase or decrease	Grand average turbidity
Toledo (Maumee River), O.	1914-29	16	147	1930-41	12	115	—32	133
Port Clinton, O.	1918-29	12	51	1930-43	14	65	14	59
Sandusky (Sandusky Bay), O.	1910-29	18	58	1930-39	8	61	3	59
Huron, O.	1917-29	12	44	1930-44	15	33	—11	38
Vermilion, O.	1917-29	12	47	1930-44	14	36	—11	41
Elyria, O.	1916-29	14	67	1930-44	15	40	—27	53
Lorain, O.[2]	1905-29	22	59	1930-44	15	30	—29	47
Avon Lake, O.	1928-29	2	78	1930-44	15	63	—15	65
Cleveland (Division Ave. Sta.), O.	1918-29	12	22	1930-44	15	14	—8	18
Cleveland (Baldwin Plant), O.	1926-29	4	16	1930-44	15	9	—7	10
Painesville (Fairport), O.	1920-29	6	39	1930-44	8	23	—16	30
Ashtabula, O.	1914-29	10	35	1930-44	15	29	—6	31
Conneaut, O.	1918-29	5	61	1930-44	12	32	—29	41
Erie, Pa.	1915-29	13	10	1930-44	15	12	2	11
All localities[3]	1905-29	11.3	52	1930-44	13.4	40	—12	45
All localities except Maumee River and Sandusky Bay	1905-29	10.3	44	1930-44	14.0	32	—12	37

[1]Years omitted if data were lacking for one or more months unless omission would have reduced number of years too greatly; no years employed when data were lacking for more than one month

[2]Data for 1905 and 1906 were obtained from the Annual Report of the Ohio State Board of Health for the years, 1906-1907, (1908). The first year following 1906 for which data are available is 1910

[3]Mean turbidities for all localities are unweighted

tion is substantiated by Chandler's data (1942a) for the open lake at Put-in-Bay, Ohio, where weekly averages of turbidities seldom exceeded 60 p.p.m., and the annual mean turbidities varied from 8 to about 30 p.p.m. in 1939-1941 as compared, for example, with the Port Clinton mean turbidities which ranged from 35 to 77 p.p.m. during these same years. Both sets of data, however, recorded the lowest turbidities for 1941 and the highest for 1939. The data of Figures 2-5 and of Tables 1 and 2 represent, then, the more turbid regions in the lake.

It may be observed from Table 1 that the mean turbidities in the inshore areas of the open lake (exclusive of Maumee River and Sandusky Bay) ranged from 10 to 67 (data for only 2 years at Avon Lake) and averaged 44 p.p.m. in the early period and varied from 9 to 65 and averaged 32 p.p.m. in the later period. The mean turbidity in the open lake decreased in recent years at all localities except Port Clinton (increase of 14) and Erie (increase of 2), and the grand average for all localities fell 12 p.p.m. This widespread downward trend (see Figs. 2-5) and the reduction in turbidity throughout the inshore waters of Lake Erie in recent years invalidate completely Langlois' theory of turbidity, for obviously if the waters have not become more roily, turbidity cannot account for any general decline in the fisheries.

It may be contended that the critical turbidities occur in the months of April and May when many species of fish hatch. An analysis of the data, however, reveals that the turbidities for these months show the same trend as the annual averages—they did not increase in recent years. The trend is illustrated by the curves of Figure 5 which depict the fluctuations in the averages for April-May at Port Clinton, Huron, Lorain, and Erie. These curves may be compared with those for the same cities in Figures 2, 3, and 4. In Table 2 the mean April-May turbidities are shown for the two series of years. It may be observed from these values that the spring turbidities (range 15-112, average 72 in early years; range 13-117, average 46 in recent years) averaged higher than the annual, but here again the mean values decreased in recent years at every locality except Port Clinton (increase of 5) and Erie (increase of 1), and the general average dropped 26 p.p.m. In fact the relative decline in turbidity values was greater for the spring (36 percent) than for the entire year (27 percent). On the basis of the data of Tables 1 and 2 and of the Figures 2-5, it must be concluded that any decline in the abundance of Lake Erie fish in recent years cannot be attributed to a general increase in turbidity. Furthermore, since the turbidities averaged well under 100 p.p.m., they in all probability were too low to affect the welfare of fishes adversely.

TABLE 2.—*Mean April-May turbidities (p.p.m.) of raw water from intakes of Ohio and Pennsylvania water plants along Lake Erie, 1910-1944*

[All intakes are located in Lake Erie proper unless otherwise stated. See map (Fig. 1) for location of cities]

Locality	Before 1930			1930 and later				
	Period of years	Number of years with data[1]	Mean turbidity	Period of years	Number of years with data[1]	Mean turbidity	Increase or decrease	Grand average turbidity
Toledo (Maumee River), O.	1914-29	16	225	1930-41	12	165	—60	199
Port Clinton, O.	1918-29	12	112	1930-43	14	117	5	115
Sandusky (Sandusky Bay), O.	1910-29	19	124	1930-39	9	92	—32	114
Huron, O.	1917-29	13	85	1930-44	15	45	—40	64
Vermilion, O.	1917-29	13	88	1930-44	15	54	—34	70
Elyria, O.	1914-29	16	102	1930-44	15	64	—38	84
Lorain, O.	1910-29	20	95	1930-44	15	44	—51	73
Avon Lake, O.	1928-29	2	132	1930-44	15	83	—49	89
Cleveland (Division Ave. Sta.), O.	1913-29	13	36	1930-44	15	21	—15	28
Cleveland (Baldwin Plant), O.	1926-29	4	28	1930-44	15	13	—15	16
Painesville (Fairport), O.	1919-29	9	51	1930-44	11	25	—26	37
Ashtabula, O.	1914-29	15	38	1930-44	15	34	—4	36
Conneaut, O.	1918-29	9	78	1930-44	13	42	—36	57
Erie, Pa.	1911-29	15	15	1930-44	15	16	1	16
All localities[2]	1910-29	12.6	86	1930-44	13.8	58	—28	71
All localities except Maumee River and Sandusky Bay	1910-29	11.8	72	1930-44	14.4	46	—26	57

[1]Years omitted if data were lacking for either month
[2]Mean turbidities for all localities are unweighted

Factors of Turbidity

Much of the discussion of this section will center about the important work of Chandler (1940, 1942a, 1942b, 1944) and Chandler and Weeks (1945) begun in September 1938 and conducted at Put-in-Bay, Ohio. Actually these authors were concerned primarily with the annual variations in the abundance of phytoplankton in the Island area of western Lake Erie and the factors responsible for those fluctuations. As part of their study, however, they presented considerable information on turbidity and undertook an analysis of causative factors. Although neither Chandler nor Weeks made any attempt to correlate their turbidity data with the survival and abundance of fishes or with the production of zooplankton, the principal food of young fishes, their researches have been cited so extensively by Langlois that my own consideration of the factors of turbidity may well begin with a critique of their studies.

Chandler stated that the materials responsible for turbidity in Lake Erie are detritus, fine sand, clay—all probably from bottom sediments—and plankton. Turbidities in the Island area over 20 p.p.m. were usually the result of storms, and readings were then uniform from top to bottom. Only when turbidities were less than 20 p.p.m. and the lake was calm did differences exist between top and bottom caused by the slow settling of suspended materials. Turbidities over 100 p.p.m. occurred only during severe storms and seldom lasted more than 2 or 3 days. In western Lake Erie turbidity is relatively high most of the year; it may be 20 p.p.m. and higher during 7 months. Winds keep the water in complete circulation most of the year. The extent of the ice-cover influences turbidity in winter by affecting wave action caused by winds. Currents, seiches, and the movement of the water mass eastward also affect the environment. In addition, "... river discharge is partly responsible for lake turbidities ..." (1944, p. 211). The author reported that "... during the first six months of 1941 each period of increased river flow was accompanied by increased lake turbidities [at Put-in-Bay]. From July to December there were few periods of heavy discharge, although lake turbidities were high during the autumn months. It appears that spring turbidities are caused primarily by suspended materials brought in by rivers but summer and autumn turbidities, although affected by rivers, are produced by other factors, the most important of which is wind action" (1944, p. 213). He concluded that "The three factors responsible for lake turbidities are plankton, precipitation, and wind" (1944, p. 229). Plankton may increase turbidity 15 p.p.m. and river discharge if dispersed throughout the lake 100 p.p.m.

Although Chandler believed he had shown that the combined discharge from five tributaries (Huron, Raisin, Maumee, Portage, and Sandusky rivers) in western Lake Erie was the major factor in the spring turbidity of the water in 1941 at Put-in-Bay, Ohio, I do not

consider his evidence conclusive at all. The very fact that the Detroit River whose waters usually are clear discharges from 97 to 98 percent (annual mean 170,000 cubic feet per second) of the combined annual mean flow of the six principal tributaries in western Lake Erie and discharged 97.5 percent of the total mean flow in the first 6 months of 1941 (Chandler, 1944, p. 212) should make one duly cautious. Chandler assumed that the five tributaries with their 2 to 3 percent of the total inflow are sufficiently turbid to affect the entire western end of the lake since "The larger tributaries flow through rich agricultural lands where erosion is potentially great" (1944, p. 210). He presented no data on the turbidity of these streams; nor did he give consideration to the fact that much of the eroded soil from these agricultural lands may have been deposited behind the numerous dams (at least 67) on these streams.[5] Michigan has 18 dams on the Raisin River system and 33 on the Huron River system. In Ohio five dams, 10 feet or higher, and at least seven dams less than 10 feet high are located on the Maumee River system, at least one 12-foot dam is found on the Portage River system, and at least three dams are situated on the Sandusky River. It is true that some of these dams were built many years ago; however, most of the early structures were mill dams of wooden construction kept in bad repair (see e.g. Ohio State Board of Health, 1899). At any rate, the modern dams must be an important factor in reducing the amount of silt that is carried into Lake Erie by the rivers.

Likewise Chandler presented no data on the dispersion of the eroded soil in the lake. It is well known that as soon as the current of a stream enters quiet water most of its suspended materials settle to the bottom (see Footnote 5). Two of the largest tributary rivers in western Lake Erie, the Maumee and Sandusky, empty into good-sized bays and their silt load is undoubtedly deposited in them.[6]

Further, it is difficult to understand how water from Sandusky Bay could affect turbidity at Put-in-Bay when the movement of the lake water is eastward (see p. 304). A similar question might be posed for the Portage River. Chandler himself stated that ". . . when the water is once east of this archipelago [the islands] it is not likely to return except under storm conditions . . ." (1944, p. 205). This eastward movement is attested to by the fact that nearly all water intakes along the south shore have been built west instead of east of the river mouths to avoid their outflows. Sanitary surveys have indicated that currents from the south-shore (Ohio) streams normally are deflected to the east and except under wind action tend to hug the shore line.

[5]Crohurst (1932) has shown that the reduction in turbidity of the Mississippi River as it flowed through Lake Pepin varied from 33 to 85 percent. On the Ohio River (Crohurst, 1933) the range of turbidity was reduced by raised navigation dams from 50-250 p.p.m. to 0-25 p.p.m.

[6]This deposition no doubt is one reason why Sandusky Bay waters are more turbid than the waters of the open lake just below its entrance and why the new water intakes of Toledo and Sandusky could be built near shore and east rather than west of the entrances of the bays as are all the other Lake Erie intakes near river outflows along the south shore (see Footnote 4).

Again, it is difficult to believe that any turbidity of the relatively small outflow from the Huron River (291 second-feet in 1940; 273 second-feet in 1941) just below the mouth of the Detroit River is not masked completely by the tremendous volume of clear water from the Detroit River (161,000 second-feet in 1940; 162,000 second-feet in 1941) long before these waters reach the Put-in-Bay area. A similar doubt may be expressed for the other Michigan streams.

Chandler drew his conclusion concerning the effect of stream discharge of lake turbidity largely from the curves in Figure 1A of his 1944 paper which depict the weekly mean lake turbidities at Put-in-Bay and the combined weekly mean discharge of the five rivers (exclusive of Detroit River) for the period, November 1940-December 1941. According to my analysis these curves show: (1) that each increase and decrease in river flow was not always accompanied by a corresponding change in turbidity even in the first 6 months of 1941; (2) that when the two curves did change in the same direction no proportional relationship existed, *i.e.,* a relatively large or small drop or rise in river discharge was not accompanied by a similar big or small change in turbidity; (3) that the fluctuations in river discharge in early 1941 were greater than those of turbidity which were insignificantly small and nearly all within a range of 5 p.p.m.; and (4) that when river discharge was relatively high (first half of 1941) turbidities were very low (usually less than 10 p.p.m.) but when the discharge was low (last half of 1941) turbidities were relatively high (usually above 20 p.p.m.). The relationship between turbidity and river discharge was not clear-cut in 1941.

Although Chandler considered river discharge to have been the more significant factor in the 1941 spring turbidities and winds the more important one in the fall turbidities, he did not separate the effects of each on turbidity. He attempted to determine the influence of winds by analyzing changes in lake levels. He asserted (1944) that most seiches with an amplitude of 0.5 foot or greater are wind-produced, that in general a wind velocity of 20 miles per hour or greater will create seiches with amplitudes of 1.0 foot or more, and that when the lake is free of ice each seiche with an amplitude of 1.0 foot or greater is accompanied by an increase in lake turbidities. He found that "... high lake turbidity during the autumn coincided with the period when lake level changes exceeded 1.5 ft. This indicates that the high winds responsible for the large seiches during the autumn months were likewise responsible for the high lake turbidities at that time" (1944, p. 217). But the author did not follow through and likewise state that low turbidities during the spring and summer coincided with the period when nearly all lake-level changes were 1.0 foot or less and that this therefore indicates that the absence of high winds was largely responsible for the low turbidities. (Winds of velocities sufficiently great to affect turbidity were present, for all of the changes in lake levels recorded in his Table 6 were assumed to be wind-produced—

amplitudes of 0.5 foot and larger.) A valid conclusion would seem to be that wind velocities under 20 miles per hour were prevalent in the spring and summer of 1941, a period of low turbidities, and that wind velocities greater than 20 miles per hour were common in the autumn of 1941 when turbidities were relatively high and, therefore, that wind action or the lack of it was the major factor in lake turbidity throughout the season of 1941. Table II of Chandler's 1940 paper indicates clearly that winds under 20 miles per hour can raise the turbidity of the water up to as high as 70 p.p.m. and that turbidities of 10 p.p.m. such as occurred in early 1941 may be associated with winds under 5 miles per hour. Even if winds had been wholly lacking, the slight variations in these low 1941 turbidities could very well have been accounted for by plankton and not, as Chandler held, by river discharge (p. 303). Chandler (1944) reported that "In 1941 the spring phytoplankton pulse was several times larger than any other one observed . . ." (p. 234) and that plankton may increase turbidity 15 p.p.m. Currents, seiches, and even bacteria might also have been involved.

It is concluded that the evidence presented by Chandler to show the effect of river discharge on the turbidity of western Lake Erie in 1941 is not convincing—too many undetermined factors and unwarranted assumptions are involved. Streams that empty into the open lake or bays or marshes soon lose whatever silt they may have. In that manner they may, of course, produce significant changes in turbidity in local areas but it is highly doubtful that such changes reach throughout the western end of Lake Erie to become a factor in the abundance of fish. But should we accept his conclusion that river discharge was largely responsible for the turbidity early in 1941, then it is perfectly obvious that the effects were insignificant (values were usually 10 p.p.m. or less).

All of the above general comments as well as most of the more specific criticisms of Chandler's studies on turbidity published in 1944 and earlier years apply with equal force to the conclusions reached by Chandler and Weeks (1945) on the factors involved in the Lake Erie turbidities in 1942. Their Figure 2D depicts the fluctuations in the combined weekly mean discharge of the Raisin, Maumee, Portage, and Sandusky rivers and the weekly mean lake turbidities at Put-in-Bay, Ohio, during 1942. On the basis of these curves the authors concluded that the spring turbidities were occasioned by river discharge and the autumn turbidities by storms. However, here again as in the 1941 data the two curves did not always correspond in the direction or the degree of change even in the early part of the year and the relationship between turbidity and river discharge was not clear-cut. In early January, late April, and early May 1942, when turbidities were relatively high, river discharges were low, and in February, when turbidities were low, river discharges were relatively high. In fact the fluctuations in turbidity throughout 1942 appeared to be

more closely associated with changes in wind velocities (as determined from lake-level variations of 0.5 foot or more in amplitude) than with those of river discharges. Since much of western Lake Erie was free from an ice cover during the winter of 1942 (p. 441 of the Chandler and Weeks paper), the winds could influence to a considerable extent the turbidity of the water even during January and February. It is unfortunate that the Ohio investigators did not correlate their turbidity data directly with wind velocities as well as with other factors.

Unquestionably wave action induced by wind is the dominant agency in erosion on Lake Erie as well as on the other Great Lakes. It is common knowledge that the shore lines of the Great Lakes have been and still are subjected to severe erosion by wave action and other agencies. White (1944) reporting on the shore erosion of Lake Erie in Ohio wrote, "Erosion of the shore is affected by a number of agencies in addition to wave attack, which is the most important. These may be listed as follows: (1) frost action on exposed surfaces, (2) surface water, (3) underground water seeping out along the bluffs, causing slumping of small or large masses, (4) ice action along the shore, (5) wave attack. Action of the first three causes above can be prevented or very materially slowed down by methods widely used by engineers for stabilization of slopes, but these methods are useless along the lake shore if direct attack of the waves is allowed to continue. . . . . Only 11 of the 184 miles of shoreline are of rock that is reasonably resistant to erosion, and even here losses are not insignificant. The remainder of the shore is weak shale, or is unconsolidated material. The annual rate of loss by erosion along the shore has been computed for various localities. At the Ohio-Pennsylvania line the average annual loss over 57 years was 2.61 feet. In Lake County average losses up to 12 feet a year occur. In Vermilion and Huron townships in Erie County an average annual loss of 5 feet over 130 years is reported. Along the Sandusky Bay shore the annual loss is 12 feet a year. At little Cedar Point in Lucas County average annual losses along the shore vary from 0.03 feet to 28.0 feet. Along the south shore of Maumee Bay over 69 years the average annual loss was 11.78 feet, and in one year, 1930, 40 feet were lost. The value of land lost annually is estimated at \$300,000, and the loss of highways and other structures adds materially to this total." It is evident that a large although unknown percentage of the bottom deposits in Lake Erie must have originated from eroded shores.

As has already been intimated (p. 302), plankton itself and probably bacteria as well (Ellis, 1937) are important and sometimes the major factors in turbidity—the more dense the crop, the greater the turbidity. Pearsall and Ullyott (1934) found that phytoplankton in Windermere Lake, England, reduced the light intensity by more than 50 percent at a depth of 4.3 metres (14.1 feet) and limited the distribution of rooted aquatic plants. Wilson (1935, 1937) reported a similar restriction on bottom plants in Little John Lake and Sweeney

Lake, Wisconsin, due to turbidity resulting from a dense crop of phytoplankton.

Reference was made (p. 300) to the eastward movement of the lake water. Chandler (1944) asserted that the water of the entire lake moves eastward at an average rate of 0.1 mile per hour. On this basis he computed that a particle of water would require about 3 months to travel from the mouth of the Detroit River to the Niagara River and that the water in the western end would be replaced each 18 or 20 days by an entirely new mass. Chandler and Weeks (1945) estimated that "Once in each 24-hour period the entire volume of water in the one area most extensively studied could be completely replaced" (p. 447). Undoubtedly turbidity in the western end is affected by this displacement of water. An unknown quantity of the finer suspensoids and microscopic organisms must be carried continually by the currents down the lake and out of western Lake Erie.

Plankton Productivity

As a major point in his theory, Langlois insists that increasing turbidities in Lake Erie have reduced plankton production to such an extent that shortages of this basic source of food have limited the abundance of fish. The mere fact that the trend of turbidities is, as we have seen, downward rather than upward invalidates this thesis entirely. I shall, nevertheless, pursue this subject further and present evidence that Lake Erie is rich, not poor, in plankton and that turbidity is not the determining factor in the basic productivity of the lake.

Before taking up these subjects I should like to interpolate certain comments on a basic weakness in Langlois' discussions, namely, that he concerned himself almost exclusively with phytoplankton and aquatic plants. Contrary to his repeated assertions (1944, 1945, 1946), phytoplankton is seldom or never used for food by the fishes in Lake Erie including the cisco (Clemens and Bigelow, 1922; Ewers, 1933; Boesel, 1938). The lake may be filled with phytoplankton and still the fish may starve.[7] It is not safe to argue that since young fishes feed on zooplankton and zooplankters feed on phytoplankton and the quantity of phytoplankton is determined to a large extent by the degree of turbidity, therefore turbidity is a major factor in the abundance of marketable fishes. Much can happen to break this long chain of events. Chandler himself, who is so often quoted by Langlois,

[7]Wilson in his Lake Erie report (1929) explained very well the relation between baby fish and microscopic plants. He wrote, "We must not infer, however, that the simple presence of such an abundance of [microscopic] plant life would provide ample food for them [fish] all. Very few of our fishes feed directly upon plants at any stage of their existence. The microscopic plants, like the Schizophyceae, the Chlorophyceae, the diatoms, the desmids, and the dinoflagellates, are too small to afford sufficient nourishment for even newly hatched fish, unless taken in impossible quantities. And the larger plants, like the algae, are not suited either to the fish's taste or to its mode of acquiring food. Hence, although plant food might be present in unlimited quantity the young fish and some of the other animals would literally starve to death" (p. 96).

discovered that in the spring of 1939 the phytoplankton pulse terminated before the zooplankton pulse began, a difference of 10 weeks existing between the maxima of these two pulses, and wrote that "Dependence of zooplankton pulses upon phytoplankton pulses is problematical . . ." (1940, p. 333).

I am, of course, fully aware, as every fishery biologist is, of the importance of plankton and vegetation to fishes and the significance of sunlight to the microscopic and larger plant organisms. However, the mere observance of fluctuations in the abundance of phytoplankton and aquatic plants and of the causal relationship between this production and turbidity is not *ipso facto* evidence that turbidity is the controlling factor in the abundance of fish—much less the marketable fish. It is still necessary to show for a depleted fishery not only that the animal-plankton crop, which is the only important component of the plankton eaten by fishes, has been reduced to the point where such food has become critically short in supply, especially at the time when needed by young fish, and that this scarcity has persisted only throughout the period of fish decline but also that the fluctuations in this plankton production and in the abundance of fish are positively correlated. Such relationship has not been demonstrated for the Lake Erie or any other Great Lakes fishes.

The available scientific evidence indicates that Lake Erie produces plankton in more than ordinary abundance. Fish (1929), for example, in a report on his survey of eastern Lake Erie wrote, "Starting with the production of food materials, as a shallow lake Erie should offer the greatest possibilities for rich animal and plant life, and our results indicate that those possibilities have apparently in no respect been diminished. The chemistry was found to be the normal chemistry of lake water, and the plankton occurred in almost unbelievable abundance. I can best describe it, perhaps, by making a comparison with the ocean. One of the richest areas of plankton life in the western Atlantic is the Gulf Stream, and yet hauls made during the same week in July with the same size and type of net in Lake Erie and in the Gulf Stream off New York City yielded the following results: In five minutes ten times the amount of plankton was obtained in the lake as in a two-hour haul in the ocean. When one considers the abundance of life which the ocean plankton supports it can be seen that certainly food is not a problem in the lake. The fish supply has diminished, but their food has not, and at the present time [1928] Lake Erie could support several times the number of fish now existing there" (p. 199).

A similar conclusion was reached by Wickliff (1931) in respect to the western region of Lake Erie. Reporting on the results of the surveys made by Ohio in the years, 1926-1930, he wrote, "The production of fish food in the form of phytoplankton, zooplankton, bottom organisms and forage fish, is sufficient to support a greater number of commercial and game fish than are now found in the lake. Quantitative fish food studies, both vertical and horizontal, and the healthy

condition of the fish examined, support this statement" (p. 200). He also reported that more species and a greater abundance of larval and young fish were taken near the main shore where pollution was suspected (and where turbidity was greatest) than in the open waters of the lake.

It is of interest to note also that Wright and Tidd (1933) who conducted a survey in western Lake Erie in 1929 and 1930 found that "The Island Section of Western Lake Erie is richer in plankton [phytoplankton] than Lake Erie east of that area, and richer than Lake St. Clair" (p. 276). They also concluded that in comparison with two typical inland lakes, representative of rich and poor waters, western Lake Erie might be described as "moderately rich" in plankton. The more recent work by Chandler (1940) in 1938-1939 showed that in these years the quality and quantity of both the phytoplankton and zooplankton in western Lake Erie were quite similar to those in 1929 and 1930. The year 1939 appeared to have been a normal one in phytoplankton production (Chandler and Weeks, 1945). These studies indicate, then, not only that Lake Erie is rich in plankton but that western Lake Erie in spite of its greater turbidity is more productive than eastern Lake Erie. It thus becomes perfectly obvious that even with plankton some factor other than turbidity dominates the basic productivity of western Lake Erie.

The evidence presented so far indicates that with respect to turbidity, conditions did not become less suitable for fish in Lake Erie in recent years as Langlois claimed. The quick changes in turbidity which he emphasized so much (p. 283) were also present in the earlier years. Not only did Lake Erie turbidities average higher in the years preceding 1930 than in those following 1929 and they therefore cannot explain any decline in the abundance of fishes in recent years, but a review of the literature (p. 288) shows that the level of turbidity in the lake (grand average of inshore waters was only 37 p.p.m.) is too low to affect the fishes adversely. These conclusions are further substantiated by a study of the Lake Erie fishes themselves including such items as growth, dominance and strength of year classes, productivity, and depletion.

Growth of Fishes

Both the so-called clean-water and tolerant fishes exhibit as good a growth in length in the turbid western waters of Lake Erie as in the clearer eastern waters of this lake or as in any of the Great Lakes or comparable waters. The species for which comparisons can be made are: walleye, sauger (*Stizostedion canadense*), yellow perch, whitefish, lake herring or cisco, sheepshead (*Aplodinotus grunniens*), white bass (*Lepibema chrysops*), and smallmouth black bass (*Micropterus dolomieu*) (Table 3). The walleyes of Lake Erie grow at about the same rate as those of Saginaw Bay but grow faster than those of Lake of the Woods. These three bodies of water are the best walleye waters

TABLE 3.—*Growth in total length (inches) calculated from scale measurements or determined from actual lengths of age groups for several species of fish from different bodies of water*

[The data of other investigators were converted when necessary to give comparable results. All fish for which age groups are used were taken late in the year except that the season of capture of the Lake Ontario herring and Reelfoot Lake sheepshead is not known; it was probably in the summer[1]]

Year of life	Calculated total length (inches)												
	Whitefish			Walleye			Yellow perch				White bass		
	Lake Erie	Lake Huron	Lake Michigan	Lake Erie	Saginaw Bay	Lake of the Woods	Lake Erie	Saginaw Bay	Green Bay	Lake Michigan	Lake Erie	Buckeye Lake, O.	Norris Reservoir (TVA)
1	6.9	5.0	6.3	6.0	6.8	6.4	3.6	3.0	2.8	2.8	4.7	6	6.3
2	12.7	8.9	9.9	9.7	10.8	9.3	6.7	5.3	4.6	4.5	8.2	10	10.5
3	16.1	12.3	13.9	12.1	13.6	11.5	8.5	7.9	6.2	6.0	10.9	13	12.2
4	18.1	16.1	17.7	15.1	15.7	13.5	9.6	9.5	7.7	7.1	12.4	....	....
5	19.6	19.2	20.3	18.0	17.2	14.9	10.3	10.6	8.8	8.5	13.2	....	....
6	20.7	21.4	22.3	....	18.5	16.7	....	11.9	10.1	9.7	13.6	....	....
7	21.4	22.9	23.3	....	19.3	18.2	....	12.8	11.0	....	14.0	....	....
8	22.1	23.9	24.0	....	20.0	19.9	....	....	....	....	....	....	....
9	22.8	24.8	24.8	....	20.6	21.6	....	....	....	....	....	....	....
10	23.2	25.3	25.4	....	....	....	....	....	....	....	....	....	....
11	23.7	25.9	26.0	....	....	....	....	....	....	....	....	....	....
12	24.2	26.6	26.5	....	....	....	....	....	....	....	....	....	....

Year of life	Calculated total length (inches)			Age group	Actual total length (inches)					
	Sauger				Lake herring			Sheepshead		
	Lake Erie	Lake of the Woods	TVA[2]		Lake Erie	Saginaw Bay	Lake Ontario	Lake Erie	Reelfoot Lake	Chickamauga Reservoir
1	5.2	4.9	8.6- 9.6	I	11.3	9.3	6.0	8.6	10.4	6.6
2	8.9	7.3	13.1-13.8	II	13.4	10.7	9.1	10.4	13.4	8.1
3	11.3	9.2	14.6-16.5	III	14.4	11.2	10.5	11.8	15.1	....
4	13.0	10.8	....	IV	14.8	11.6	10.9	13.2	15.9	....
5	14.2	12.3	....	V	17.6	12.1	11.8	14.3	18.1	....
6	15.8	13.2	....	VI	19.8	12.9	12.6	16.1	20.1	....
7	....	....	....	VII	17.9	14.4	13.8	16.3	....	....
8	....	....	....	VIII	....	....	14.1	17.6	23.3	....
9	....	....	....	IX	18.1	....	16.7	....	....	....

[1] I am indebted to Dr. Ralph Hile for the compilation and conversion of the data in this table.
[2] Extremes for three reservoirs.

in the Great Lakes area. The Lake Erie saugers grow more rapidly than those of Lake of the Woods, the only other important sauger waters in the Great Lakes region. The saugers of the TVA reservoirs, however, show a greater rate of growth. The growth of yellow perch in Lake Erie exceeds that of the perch in Saginaw Bay, Green Bay, and northern Lake Michigan, the principal perch-producing areas in the Great Lakes. The Lake Erie whitefish grows much more rapidly than the whitefish of Lake Huron and Lake Michigan. The Lake Erie herring has a decidedly much faster growth rate than the herring in Saginaw Bay and Lake Ontario. The sheepshead, a tolerant form, grows more slowly in Lake Erie than in Reelfoot Lake but the Erie fish grow more rapidly than the sheepshead in Chickamauga Reservoir (TVA); no comparisons are available between northern waters. The Lake Erie white bass appear to grow more slowly than those of Buckeye Lake, Ohio (data are approximations) and the southern waters of the TVA. The smallmouth black bass of the Island Region in western Lake Erie have been found to grow faster than those investigated from 13 lakes and rivers in Ontario, Ohio, and Quebec (Doan, 1940). Thus, the data indicate that the growth of the first-choice fishes in the turbid western waters of Lake Erie exceeds in nearly every instance the growth of these fishes in the clear waters of the Great Lakes or adjacent waters. Turbidity has not created an unsuitable environment for the growth of these fishes in western Lake Erie.

Fluctuations in the Strength of Year Classes

Phenomenally strong year classes of 1926.—Langlois maintains that in Lake Erie the strength of year classes and turbidity are causally related. To support this view he has referred to the year classes of 1926 which have been shown to be the most outstanding with respect to the survival of fishes in Lake Erie. Never since that time has there been such a phenomenal production of juvenile fishes. Every species that we investigated found conditions favorable for survival. They included both the so-called clean-water forms (walleye, blue pike (*Stizostedion vitreum glaucum*), yellow perch, white bass, whitefish, cisco) and the alleged tolerant varieties (sauger, sheepshead) and both spring spawners and fall spawners (whitefish, cisco). Langlois (1941) suggested that the phenomenal survival among the walleyes might be correlated with clear-water conditions. Figure 1 published by Doan (1942) as well as my data (Fig. 5) indicate clearly that spring turbidities were not relatively low in western Lake Erie in 1926. In fact in that year the turbidity at Port Clinton reached the highest on record. My data show the following 1926 spring (April-May) turbidities (first figure) for western Lake Erie as compared with the grand averages for each port (second figure): Port Clinton, 178 and 115; Huron, 74 and 64; Vermilion, 81 and 70. It is evident that the big crop of fishes in 1926 was not associated with unusually

TABLE 4.—*Dominant year classes and age groups in the commercial catch of eight species of fish in Lake Erie, October-November, 1943-1946*[1]

Species	Number of fish	Year of catch	Dominant group: Year class	Dominant group: Age group	Dominant group: Percentage of sample	Second strongest group: Year class	Second strongest group: Age group	Second strongest group: Percentage of sample	U. S. production in pounds
Blue pike	706	1943	1939	IV	58	1940	III	38	Heavy (11¼ million)
	264	1944	1940	IV	59	1939	V	23	Heavy (15 million)
	474	1945	1941	IV	38	1943	II	26	Below average (7¾ million)
						1940	V	24	
	338	1946	1944	II	56	1943	III	17	Very light (3 million)
Cisco	136	1943	1941	II	61	1942	I	31	Second lowest on record (26,000)
	2	1944	1943	I	100	....	....	....	Very low (98,000)
	339	1945	1944	I	98	1943	II	2	Marked increase (2¾ million)
	83	1946	1944	II	98	1945	I	2	Much heavier (6 2/3 million)
Sauger	79	1944	1942	II	95	1941	III	5	Second lowest on record (616,000)
	216	1945	1942	III	70	1943	II	29	Average (1 million)
	97	1946	1943	III	61	1944	II	24	Light (762,200)
Sheepshead	59	1943	1936	VII	30	1937	VI	25	2d highest on record (4½ million)
	54	1944	1938	VI	44	1941	III	13	Normal (2½ million)
	158	1945	1939	VI	29	1938	VII	27	Heavy (4½ million)
	168	1946	1944	II	32	1942	IV	24	Heavy (4¼ million)
White bass	134	1943	1942	I	73	1941	II	24	Normal (460,000)
	78	1944	1943	I	80	1942	II	20	Very good (860,000)
	153	1945	1944	I	60	1943	II	31	Very good (883,000)
	134	1946	1945	I	48	1944	II	48	Very good (821,300)
Whitefish	162	1943	1938	V	38	1937	VI	35	Low (949,000)
	7	1944	1941	III	57	....	....	....	4th lowest on record (567,000)
	140	1945	1942	III	63	1941	IV	29	Low (900,000)
	123	1946	1943	III	38	1942	IV	37	Low (797,000)
Yellow perch	174	1943	1941	II	49	1942	I	22	4th lowest on record (1¼ million)
						1940	III	22	
	136	1944	1942	II	80	1941	III	18	Fair (2¼ million)
	232	1945	1942	III	52	1943	II	38	Very low (1 1/3 million)
	433	1946	1944	II	72	1943	III	23	Average (2 2/3 million)
Walleye	109	1943	1940	III	49	1941	II	25	Very good (3¼ million)
						1939	IV	23	
	78	1944	1942	II	72	1941	III	12	Very good (3½ million)
						1940	IV	10	
	334	1945	1942	III	53	1943	II	34	Very high (5 1/3 million)
	219	1946	1943	III	39	1944	II	32	Highest on record (6¼ million)

[1] I am greatly indebted to Dr. Frank W. Jobes for the age analyses of these fish

clear-water conditions in the spring but with higher-than-average turbidities.

Failure of Langlois' prediction as to the strength of the 1941 year classes.—The spring turbidities of western Lake Erie were exceptionally low in 1941 (Chandler, 1944) and on this basis Langlois (letter, July 8, 1941, to Board of Inquiry; Ohio Conservation Bulletin, 1943, 1945) predicted that the 1941 year classes would be abnormally abundant and would dominate the commercial take over a period of years as was true for the 1926 broods. Age analyses of the commercial catches of 1943, 1944, 1945, and 1946, however, do not indicate unusual survival in 1941. In Table 4 are shown for eight important species not only the dominant year classes in the catch but also the second strongest year classes. The data reveal that 1941 was not an outstanding year for survival of fish. If it had been, the 1941 year class should have been recorded as dominant about 18 times in Table 4; it appeared only 4 times. It dominated the 1945 catch of blue pike, which was below average, but not the yields of 1943 and 1944, years of extremely heavy production. It also dominated the 1943 catch of ciscoes but the yield was the second lowest on record (26,000 pounds). It contributed only 5 percent to the 1944 catch of saugers, the second lowest on record. The 1941 year class was the second strongest in the 1944 production of sheepshead (13 percent) and in the 1943 catch of white bass (24 percent), but the take of each was only normal in size. This year class probably was also most abundant in the 1944 take of whitefish (only seven fish in sample) and was second strongest (29 percent) in the 1945 production. But here again the output was extremely light being the fourth lowest on record in 1944 (567,000 pounds). Similarly the 1943 lifts of yellow perch were dominated by the 1941 fish, but the catch was the fourth lowest on record (1¼ million pounds). In 1944 this year class was the second strongest (18 percent) in an annual yield that was only fair. It was also the second strongest in the production of walleyes in 1943 (25 percent) and 1944 (12 percent), years of very good yields.

In the blue pike, whitefish, and yellow perch productions of 1945, 1944, and 1943 respectively, the 1941 year class was expected to be most abundant in accordance with the normal age distribution in the commercial catch. For this same reason this year class was also expected to rank second in strength among certain species in certain years (sauger, white bass, whitefish, yellow perch, walleye). Studies indicate, then, not only that the 1941 year classes were not large but when they did predominate, the yields were all below average or very close to the lowest on record. Langlois' widely publicized prognostication failed to materialize.

Turbidity and survival in certain other years.—It is also of interest to note in Table 4 that the 1942 year class was the only one, except the 1944 class of ciscoes, that dominated the commercial yields in two successive years thus suggesting a relatively good survival in that

year. This year class dominated the 1944 and 1945 catches of sauger (an alleged turbid-water form), yellow perch, and walleyes (clean-water forms). The apparent relatively good survival in 1942 (associated with large yields only in the walleyes and sheepshead) was, however, not correlated with unusually low turbidities, although they did average below the general mean, nor with a great abundance of plankton in the spring which according to Langlois (1946) amounted to only 16 percent (Chandler and Weeks gave a value of 19 percent) of the maximum amount in 1941 which he used as a standard.

It has been asserted (Langlois, 1945) that in the springs of 1938 and 1939 the Lake Erie water was very muddy and conditions were most unfavorable for survival of young fishes, especially whitefish and walleyes. Table 4 shows, however, that the 1938 year class (age-group V) dominated the whitefish catch in 1943 in spite of the fact that normally the III-group fish are most abundant in the catch. This year class also dominated the 1944 catch of sheepshead and nearly dominated the 1945 take. Similarly the 1939 year class was most abundant in the lifts of blue pike in 1943 and ranked second in strength in 1944; it also dominated the catch of sheepshead in 1945 and almost ranked second in the 1943 yield of walleyes; in each of these cases production was heavy.

The year 1944 seemed to have been rather favorable to the survival of Lake Erie fishes as judged by dominance alone (Table 4). This year class dominated the yields of blue pike, sheepshead, and yellow perch in 1946, of ciscoes in 1945 and 1946, and of white bass in 1945 (nearly in 1946). It was second strongest in the catch of saugers (24 percent) and of walleyes (32 percent) in 1946. However, such dominance or strong representation was to be expected on the basis of normal age distribution in the take of yellow perch, ciscoes, white bass, saugers, and walleyes. Predominance was not always associated with heavy production. Records indicate that the yields of blue pike and saugers were very light and those of the sheepshead, ciscoes, and walleyes were heavy. The production of yellow perch was about average and the take of white bass was above average. The data indicate, then, that the 1944 year class was strong in the cisco, white bass, walleye, and perhaps sheepshead.

What about the turbidity in 1944? The annual mean turbidity of the Ohio waters in that year was 25 p.p.m. as compared with its grand average of 41 (excludes Erie, Pa.) and with 20 p.p.m. in 1941, a year in which the water was exceptionally clear. The April-May turbidities of these same waters averaged 42 p.p.m. in 1944 as compared with the grand average of 65 and with 16 p.p.m. in 1941. The turbidity in 1944 was relatively low but not nearly as low as in 1941.

It is of special interest to note here the recent remarkable though temporary return of the whitefish and the increase in the catch of the cisco in Lake Erie. During the period, 1879-1938, the average production of whitefish in the entire lake (United States and Canada) was

2,259,207 pounds. In the years, 1939-1942, however, every year yielded more than four million pounds with an average of 5,110,493 pounds. Only once before (in 1914) did the catch exceed four million pounds. In 1943-1946 the take returned to or below the average. Similarly during the period, 1879-1924, the catch of ciscoes averaged 26,557,943 pounds (United States and Canada). Then the yield dropped suddenly in 1925 to 5¾ million pounds and continued to decrease to an average of 227,520 pounds in 1933-1937. In 1938 and 1939 there was a partial recovery to an average of 2,437,150 pounds when production again declined to below 90,000 pounds in 1942 and 1943, the two lowest on record. In 1944 the take increased to 433,996 pounds and according to reports from the fishermen and the available United States statistics the 1945 and 1946 yields reached somewhere between five and ten million pounds (the 1945 catch in United States waters was 2,764,800 pounds and the 1946 yield was 6,638,400 pounds).

These recoveries are interesting in view of Langlois' statements (p. 283) that these species "appear to be approaching extinction" because Lake Erie has been changed from a suitable habitat for them due to increased turbidity and deposition of silt "over the hard bottoms around the islands." The mere facts that these two members of the whitefish family which spawn in the fall and hatch in the spring did return in abundance and did not do so in exactly the same years of hatching indicate in themselves that neither turbidity nor deposition of silt was responsible for their decline. Or must we believe, despite all evidence to the contrary, that the allegedly silted bottoms suddenly cleared up for a few years (1936-1938 or 1939 and 1944) and that turbidity decreased during that time?

A small sample of whitefish taken in 1939, the first year of heavy production, and aged at the Put-in-Bay, Ohio, laboratory indicated that the III group dominated the catch in that year. We found dominance by this group to be characteristic of the whitefish population in Lake Erie. We may believe, then, that most of the whitefish marketed in 1939 were hatched in 1936 and that most of those taken in 1940-1942 must have been hatched in later years—1937, 1938, and possibly 1939. Since the dominant groups in 1943 were old fish, contrary to normal conditions (Table 4), and belonged to the 1937 and 1938 year classes, it is probable that the 1939 year class was a weak one. At any rate it appears certain that the year classes, 1936-1938, were unusually strong.

What were the conditions in those years with respect to turbidity and silt deposition? The Ohio data on turbidity show that none of these years was characterized by unusually clear water. The average annual mean turbidity of the Ohio waters for the years, 1936-1939, were 42, 45, 48, and 40 p.p.m. respectively as compared with the grand average of 41, and the April-May averages for these years were 61, 64, 59, and 69 p.p.m. respectively as compared with a grand average of 65. Turbidity was, therefore, not a factor in the survival of whitefish in

1936-1939 and in the subsequent heavy production of this species in the years, 1939-1942. With reference to silt deposition Shelford and Boesel's Figure 4 (1942) indicates that at least in 1937 all bottoms surrounding the islands were either hard or sandy, that a large area of the more open water also had a sandy bottom, and that only the deeper, more quiet waters had soft bottoms consisting largely of plant debris (even at a depth of about 5 inches nearly half of the bottom mud consisted of plant detritus). No evidence exists that these bottoms change materially from year to year.

How about the cisco? Age analysis for a few ciscoes taken in August 1938, at Port Dover, Ontario, showed that these individuals which ranged from 6.7 to 8.3 inches in length were I-group fish hatched in 1937. This size group of the 1937 year class no doubt entered the catch in 1939. Of seven ciscoes in a 1938 sample from a commercial lift off Cleveland, Ohio, four belonged to age group II and were hatched in 1936 and three were I-group fish hatched in 1937. No 1939 samples were analyzed. We found that in earlier years the cisco catch was characteristically dominated by I- and II-group individuals. We may assume then that the bulk of the 1938 and 1939 yields of ciscoes was made up of fish hatched in 1936 and 1937 and possibly in 1938. However, if the 1938 year class had been unusually strong the 1940 production should have been large—which it was not. As already shown above, the average turbidities in 1936-1938 did not indicate unusually clear water in Ohio during that period.

With respect to the 1944-1946 yields our age analyses show that in 1944 the cisco catch consisted almost entirely of I-group fish (only two fish in sample) hatched in 1943 (Table 4), that in 1945 the yield was made up of nearly all I-group individuals hatched in 1944, and that in 1946 the take comprised almost wholly II-group fish also hatched in 1944. Since the production of ciscoes in 1944 was not large (433,996 pounds) and the 1943 year class made up only 2 percent of the 1945 catch, it appears that the year 1943 was not particularly favorable to ciscoes. The year 1944, however, seemed favorable for survival of ciscoes. Turbidities were relatively low for Ohio waters in 1944, the annual mean being 25 p.p.m. as compared with the Ohio grand average of 41, and the April-May average being 42 p.p.m. as compared with the grand average of 65. These data suggest that some relationship may have existed between turbidity in 1944 and the abundance of ciscoes in 1945 and 1946. However, immediately the question arises why did not the ciscoes, as well as the whitefish, also show increased survival in such years as 1935, 1940, 1941, and 1942 when turbidities were nearly as low as or lower than those in 1944 (annual means—30, 27, 20, and 35 p.p.m.; April-May averages—48, 39, 16, and 53 p.p.m. respectively)? And conversely why was there no correlation between the strong year classes, such as those of 1926, already discussed above and turbidity? And why did the whitefish whose

spawning and feeding habits are similar to the cisco not produce a large year class in 1944?

On the basis of the above discussion it is concluded that turbidity was not responsible for the recent rise in production of either the whitefish or the cisco in Lake Erie since (1) no relationship could be demonstrated between the increased survival of whitefish in 1936-1938 (1939?) and turbidity or (2) between the increased survival of ciscoes in 1936-1937 (1938?) and turbidity and (3) neither the whitefish nor the cisco increased in abundance in those years when turbidities averaged lower than or approximated those of years in which survival was unusually good.

It is perhaps not necessary to point out in great detail other failures of the Lake Erie species to conform with Langlois' theory and statements with respect to production and abundance. He suggested (see p. 283) that turbid waters and the silt loads from the Maumee River may well account for the decline of the walleyes, that yellow perch are diminishing in numbers because of the scarcity of vegetation, that saugers, sheepshead, catfishes (*Ameiuridae*), and carp (*Cyprinus carpio*) appear to thrive in turbid water and have increased in the catch. None of these assertions with respect to catch can be supported by statistics except for the sheepshead. In 1937 and each year thereafter the so-called clean-water walleye produced in excess of 3¼ million pounds in Lake Erie which total was never exceeded before 1937. The yield reached an all-time high in 1946. During the period, 1928-1935, the catch of yellow perch, also a clean-water fish, exceeded by far any ever recorded before or after these years. On the other hand, the so-called turbid-water species—saugers, catfishes (including bullheads), and carp—yield much less now than in the early years of the fishery. The production of sheepshead like that of the walleye has increased in the last few years. As judged by the catch records of these species specifically mentioned by Langlois, it would appear that the so-called clean-water varieties were doing fully as well as, if not better than, the allegedly more tolerant forms, thus suggesting that Lake Erie has not become more roily in recent years.

The evidence presented in this section demonstrates clearly that turbidity is not a major limiting factor in the abundance of fish in the commercial catch of Lake Erie, and predictions of abundance based on turbidity are purely speculative. In view of these findings, it is not surprising, therefore, that Doan, an Ohio investigator, (1941, 1942) failed to demonstrate statistically a causal relationship between turbidity in April-May of a particular year and the yield in subsequent years of several species of fish in Lake Erie. He could find no such relationship for the yellow perch, walleye, and blue pike. He did, however, report it for the closely related sauger in spite of the very low average turbidities of 25 p.p.m. or less (one year averaged 44 p.p.m.). However, his data for the sauger indicated

a positive, not a negative, correlation between high turbidity and the subsequent catch. Doan's results must be disconcerting to those (particularly the Ohio officials) who have persistently maintained that soil erosion is a major and detrimental factor in the abundance of Lake Erie fishes.

Fish Productivity

Lake Erie, although the most turbid of the Great Lakes, is also the most productive in fish, and the most roily section of the lake, the western end, contributes the greatest share of the annual catch. For example, in 1943 the fishermen from Huron, Ohio, and west thereof (see Fig. 1) produced 54 percent (14,581,654 pounds) of the entire United States catch in Lake Erie and 67 percent of the Ohio catch. Before the collapse of the cisco fishery in 1925, the United States waters of Lake Erie contributed 47 percent to the total United States production on the Great Lakes; they still contribute more than those of any of the other Great Lakes—33 percent. Both clear-water and tolerant forms multiply and thrive in western Lake Erie in large quantities. This region is also noted for its excellent fishing for smallmouth black bass, a decidedly clean-water form, and is undoubtedly the most prolific producer of fish found anywhere in the Great Lakes.

As judged by certain accepted standards of water suitability for fishes (p. 287) that have been established on the basis of the existence of a good mixed fish fauna in a lake or stream, conditions in Lake Erie must be considered highly favorable for fish, and the turbid western end must be judged to be the best section in the lake. For example, in this section some 22 species make up in considerable numbers the commercial catch, whereas only 14 varieties compose the lifts in the eastern area.

Depletion of Fishes

Finally it should be pointed out that fish have decreased in abundance in the crystal-clear waters of the other Great Lakes as well as in the less clear waters of Lake Erie. Both clean-water varieties such as the Erie cisco and the alleged more tolerant forms such as the Erie sauger have suffered a decline. Some species as the deep-water chubs and ciscowet trout spend their entire life in water 300 feet and deeper. Environmental conditions, even including temperature, remain quite stable at these depths. And yet—these fishes have suffered a decrease in abundance in recent years. Only fishing can explain this reduction —turbidity cannot. Further, the serious depletion of such clean-water species as the chubs of Lakes Michigan and Huron, Lake Huron whitefish, and Lake Erie cisco has definitely been associated with increased fishing effort (Van Oosten 1930; Van Oosten, Hile, and Jobes 1946). Turbidity could not possibly account for the reduction of all Great Lakes fishes even though we accepted it as the cause of decrease in Lake Erie. As a matter of fact, the only known factor that can reasonably explain the long-term declines for most of the species in these

lakes is fishing; the continual removal each year by fishermen of large quantities from a depleted stock must certainly have some effect on its abundance in the lake.

In conclusion I wish to state that although it is perfectly clear that soil erosion on our farms and turbidity of the water are not major factors in the decrease in abundance of our Great Lakes fishes, the environment is nevertheless an important element in the welfare of these fishes. We may not be able to discover the controlling factor in any one year. Perhaps this factor changes each year. Perhaps a mosaic of factors is involved. At any rate, to changes in environmental and ecological conditions we must undoubtedly ascribe to a large degree the natural annual fluctuations in abundance that occur whether the fish are plentiful or scarce, whether they live in clear or turbid waters or in streams, lakes, or oceans. Our chief concern, however, is with the long-term downward trends in yield and the complete collapse of a fishery due to man's activities, not these short-term natural fluctuations in abundance which are beyond our control in such large bodies of water as the Great Lakes. I do not mean to imply, however, that we do not need to study these natural fluctuations and their causes. By understanding and evaluating the relative importance of each factor involved in variations of abundance we may judge better what results may be expected from specific management practices. We cannot change the weather or control the winds. Yet a knowledge of the effects of these and other uncontrollable agencies on the success of year classes enables us to appraise more intelligently the results of changes in regulatory measures on size limits, closed seasons, mesh in gear, type of net, and other restrictions on fishing pressure.

Summary and Conclusions

The occasion for the preparation of this paper was the widespread publicity that has been given Langlois' theory which holds: that turbidity is the major factor in the abundance of Great Lakes fishes, especially in Lake Erie; that turbidities have risen as the result of increased soil erosion in agricultural regions draining into Lake Erie, thus rendering it an unsuitable habitat for first-choice species; and hence that materials carried into the lake by tributary streams and not destructive fishing practices must be held responsible for the decline of the fisheries. I am compelled to demonstrate the utter invalidity of Langlois' views since acceptance of his theory would entail abandonment of the vitally important program of conservationists to correct fishing abuses on the Great Lakes and bring the fisheries under a practical and scientific management.

High tolerance of fishes toward turbidity.—Although no exact standard of tolerance can be fixed, it is apparent from the available quantitative information that fish, even the so-called clean-water species, are far more tolerant of turbid waters than is commonly

supposed. They live and thrive in waters with turbidities that range above 400 p.p.m. and average 200 p.p.m. Even much greater values could not be shown to interfere with feeding or growth. In some situations high turbidity actually can be beneficial by protecting young fish from predators, or the suspensoids may provide a base for a coating of bacterial jelly which may be an important basic source of food. There is no evidence that turbidities of less than 100 p.p.m. affect adversely the production of fish.

Low turbidity values in the Great Lakes; downward trend of turbidity in Lake Erie.—All of the Great Lakes except Erie have extremely clear water. The turbidity of the open waters of these lakes probably averages less than 10 p.p.m. and of the inshore waters no more than 20-25 p.p.m.—values far too low to be considered important as a factor in any decline of the fisheries. Lake Erie is somewhat more turbid than the other Great Lakes. The grand average annual turbidity of inshore waters (based on samples of raw water from various city intakes in Ohio and Pennsylvania, mostly located 1/4 mile or less from shore and at most under 4½ miles) was 37 p.p.m. The trend of turbidity has been downward since the annual values averaged 44 p.p.m. before 1930 as compared with 32 p.p.m. in 1930 and later years. The April-May turbidities, which might be considered more significant as many fish hatch in those months, averaged somewhat higher (57 p.p.m.). The long-term trends were the same, however, as with the annual turbidities, for the average before 1930 (72 p.p.m.) was substantially greater than that for 1930 and later (46 p.p.m.). Even these higher values in Lake Erie are most probably too low to have any important effect on the abundance of fish. This fact and the downward trend in turbidities are sufficient in themselves to invalidate completely the Langlois theory.

Relative unimportance of soil erosion on farm lands as a factor in turbidities of Lake Erie.—A major point in the Langlois theory, the assumption that stream-borne suspensoids determine turbidity values, has been based largely on the work of Chandler in western Lake Erie. Chandler believed that turbidities of the island region were determined largely by wind action in the summer and fall, whereas spring turbidities depended primarily on suspended materials brought in by rivers. A critical analysis of Chandler's work gave no reason for disagreement with his conclusions as to the cause of late-season turbidities. His belief that spring turbidities are caused chiefly by materials carried in by rivers cannot, however, be accepted. Chandler failed to consider or did not give proper weight to such factors as: the obvious lack of close correlation between his curves for turbidity and river discharge; the fact that turbidities were higher in the fall of 1941 when river discharges were low than in the spring when the discharges were high; the enormous diluting effect of the clear waters of the Detroit River which supply 97-98 percent of all water flowing into western Lake Erie as compared with only 2-3 percent from the five "muddy"

streams; the extensive settling out of suspensoids behind the numerous dams on tributary streams or in the bays and marshes through which the streams pass before they reach the lake; the normally eastward movement of water that would tend to carry the discharge of south-shore streams down the lake and away from the island region. The turbidity values and the fluctuations of turbidity that Chandler observed in the spring of 1941 can be accounted for adequately as the result of wind action and plankton bloom; evidence that river discharge played a significant role is lacking. The additional data provided by Chandler and Weeks for the year 1942 strengthened the belief that wind action is the dominant factor in turbidity at all seasons of the year.

Data on the extent of bank erosion in Lake Erie suggest that the shores of the lake rather than soil from the agricultural lands of the drainage area are the principal source of suspensoids. Bank erosion has, of course, been taking place since the lake was first formed.

Suitability of Lake Erie as a fish habitat.—Langlois' belief that increasing turbidity made Lake Erie an unsuitable habitat for first-choice species was given a death blow by the proof first that turbidity values even in this, the most roily of the Great Lakes, are most probably too low to affect fish adversely and second, that the trend is toward lower turbidities. If habitat conditions have deteriorated in Lake Erie, turbidity is certainly not a factor. All available evidence indicates, however, that Lake Erie provides an excellent habitat for fish. In comparison with other waters the production of plankton, basic source of food, must be judged as extremely high, and the more turbid western end is the more productive. Even more significant is the fact that Erie, though next to the smallest of the Great Lakes, far outranks any of them in the output of fish—and again the heaviest production is in the more turbid, westerly waters. Finally, the growth of Lake Erie fishes, including the clean-water species, compares most favorably with that in other waters.

Absence of correlation between turbidity and the strength of year classes.—According to the Langlois theory, turbidity conditions control abundance by determining the success of reproduction (hatching and survival of young fish). It is alleged that if the waters are exceptionally turbid (particularly in the spring when most fishes spawn) the year classes will be weak whereas low turbidities are conducive to strong year classes. On the basis of the unusually clear water in the spring of 1941 Langlois predicted that the year classes produced in that season would be outstandingly strong and would dominate the commercial take over a period of years. Extensive age determinations for samples of fish from the 1943-1946 commercial catch revealed, however, that this much publicized prognostication was grievously in error. The 1941 year classes were not exceptionally strong; if anything, they were weaker than average. On the other hand, the strongest year classes of which we have any record, those of 1926, were hatched

in a year in which spring (April-May) turbidities were above average.

Data on the above and other year classes together with the examination of production statistics in the light of the year classes that probably contributed to certain exceptional yields led to the conclusion that no clear-cut relationship exists between turbidity and the success of reproduction. Strong and weak year classes appear to be produced indifferently in clear-water and turbid-water seasons.

Overfishing as the major cause of depletion of the Great Lakes fisheries.—Langlois' theory that turbidity is responsible for the decline of Lake Erie fisheries is again made untenable by the fact that certain clean-water species, such as the walleye and whitefish, are now or have been within recent years at a high level of abundance whereas some of the supposedly tolerant varieties, as the sauger and carp, are yielding much less than in earlier years. Furthermore, declines in production have by no means been confined to the relatively turbid Lake Erie but have occurred in all of the Great Lakes and have affected all types of fish, including even the deep-water chubs which live in an almost changeless environment. The one common feature of these declines has been an increase of fishing pressure. The sequence of more intensive fishing and a drop in abundance and production has been observed in the Great Lakes far too frequently to leave any doubt concerning the role of overfishing as the major cause of depletion.

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THE FAILURE OF RAINBOW TROUT AND INITIAL SUCCESS WITH THE INTRODUCTION OF LAKE TROUT IN CLEAR LAKE, RIDING MOUNTAIN PARK, MANITOBA

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Abstract

In 1936, after a biological survey and a consultation of several fish-culturists, it was decided to attempt the introduction of rainbow trout (*Salmo gairdnerii*) into Clear Lake. This decision was influenced by the urgent need for a suitable game fish in this lake, the chief resort in Riding Mountain Park, and by the wish to check the feasibility of rainbow trout for stocking in lakes of this life zone. Planting, in the years 1937 to 1942 was carried on according to a plan which made use of rearing ponds to increase the size of the fish ıeleased. In 1942, when it was found that the rainbow trout were not surviving, it was recommended that planting be discontinued and an attempt made to establish lake trout (*Cristivomer namaycush*). After three years of planting with adult lake trout it was found that they were surviving in the lake but as yet no evidence of spawning has been obtained. In this report the physical and biological conditions in the lake are described and discussed in relation to the fish-culture experiments. It is concluded that great difficulty will be encountered in attempting to introduce rainbow trout into lakes in which a heavy population of competitor and predator fish is already present.

Introduction

Since the rainbow trout is recognized as one of the best game fish on the continent it is natural that there should be frequent requests for stocking new areas with this species. It is thus desirable that controlled test plantings should be made in representative areas as a guide to further stocking and to avoid unnecessary waste of effort and funds. Such an experiment has been carried out in Clear Lake, Riding Mountain Park, after a biological survey in 1935. The results are of interest in suggesting difficulties which may be encountered in the introduction of rainbow trout into other waters of the prairie provinces.

Examinations of Clear Lake were made by A. Bajkov, University of Manitoba, in 1932 and 1933, by J. Martin, Superintendent of the Banff Hatchery, in 1934 and by the writer in 1935. The decision to plant rainbow trout and the method of planting were worked out in consultations between J. A. Rodd, Supervisor of Fish Culture, Department of Fisheries, Ottawa, the writer and C. McC. Mottley. The latter's experience in rainbow trout culture in British Columbia was the basis for the stocking plan. Follow-up studies were made by H. Rogers, National Parks Bureau, in 1940, by the writer in 1942 and by K. H. Doan, Central Fisheries Research Station, Winnipeg, in

1945. In the following account information as to the nature of the lake and its fish fauna is drawn largely from the writer's observations. Reports from the investigators mentioned above are on file at the National Parks Bureau, Department of Mines and Resources, Ottawa. Bajkov (1929) described the whitefish from Clear Lake but no account of the fish-culture experiments has yet been published. Grateful acknowledgement is made to Dr. K. H. Doan for making available the results of his 1945 investigation.

Geographic, Physical, and Biological Conditions in Clear Lake

Location.—Clear Lake lies in the southwest part of Manitoba, in the Riding Mountain National Park. The Park is in the Canadian Life Zone and in what Halliday (1937) describes as the Mixedwood Section of the Boreal Forest Region. This section is characterized by mixed stands of poplar and spruce. It extends far west and north including such well known lake areas as the Prince Albert National Park, Cold Lake on the Saskatchewan-Alberta Boundary, and Lac La Biche in Alberta.

The lake is at the relatively high altitude of 2,100 feet, near the eastern edge of the second prairie steppe. The boundary of this steppe is an escarpment about one thousand feet high, which marks the western boundary of the former glacial Lake Agassiz. Lying on the plateau near this escarpment, Clear Lake has a very small drainage area, about 75 square miles. Cutting and fires have destroyed some of the forest cover but approximately three-quarters of the drainage area is still forested. The annual precipitation in this area is about 17 inches per year. The mean annual temperature is in the neighborhood of 33°F. (0.6°C.).

Morphometry and shores.—Clear Lake has a length of 6.5 and a greatest width of 2.5 miles (Fig. 1). The long axis is to the northwest, in the direction of the prevailing winds. The area is 9.5 square miles and the shore length about 20 miles. Most of this shoreline is regular and exposed. About 60 percent of the shore is of coarse gravel and stones, 30 percent of sand, and 10 percent sand or mud with emergent vegetation, chiefly the bullrush, *Scirpus* sp. Most of this vegetation is in the large shallow bay to the northwest.

The lake was sounded and depth contours were plotted at 5-meter intervals. The maximum depth observed was 31 meters, found both in the narrow bay to the east and in the open lake about 2 miles northwest of the townsite. The relative areas of the depth zones have been calculated as follows: 0 to 5 meters—25 percent, 5 to 10—20 percent, 10 to 15—16 percent, 15 to 20—13 percent, 20 to 25—10 percent, 25 to 30—10 percent, 30 to 31—6 percent. The mean depth was 13.2 meters or 43 feet.

Drainage and water level.—Five or six small streams enter the lake. Three of these arise from springs not far from the lake and flow con-

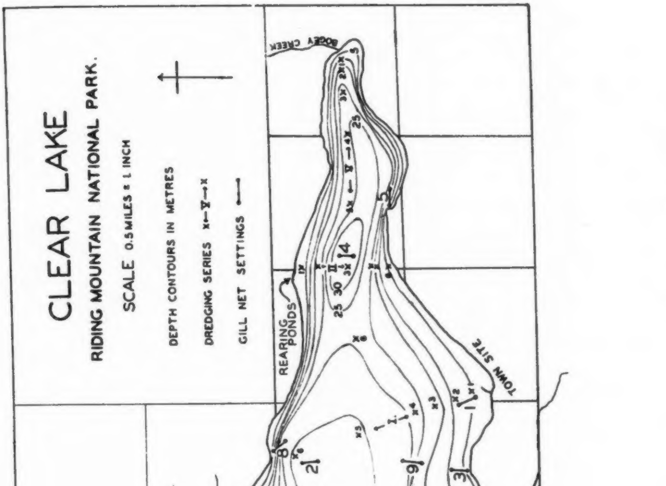

FIGURE 1.—Map of Clear Lake showing depth contours and location of stations.

tinuously. The others depend chiefly on surface drainage and have thus only intermittent flow. The outlet stream, known as Wasamin Creek, drains into the Minnedosa and thence to the Assiniboine River. From 1930 to 1942 there was no outflow and the water level dropped at least 2 feet. Some improvement was noted in 1944 and by June 1945 the former level was restored and there was a substantial outflow. High levels were maintained in 1946.

The effects of lowered water levels were observed in the salt concentration of the lake water and in the cutting off of South Lake, a weedy area, formerly an important spawning ground of the northern pike (*Esox lucius*).

Physical and chemical conditions.—The lake is frozen over for at least 5 months of each year, ice forming about the first of December and breaking up early in May. Summer temperatures have been observed from May to September and selected series are recorded in Table 1 and Figure 2. The observations for 1932 and 1933 are from Bajkov's manuscript reports for those years. It will be seen that surface temperatures vary from 5.1°C. in mid-May to a maximum of 21.5° in July. Bottom temperatures ranged from 4.5 to 12.0°C. The lake remains nearly homothermous until the middle of June but develops a marked stratification with a thermocline between 10 and 20 meters in July and August. Observations on September 5, 1932, show that the stratification had been destroyed prior to that date. This thermal cycle is much like that found in Waskesiu and other lakes of the Prince Albert Park by the writer (Rawson, 1936). Transparency, measured by a Secchi disc, ranged between 4 and 5 meters.

TABLE 1.—*Temperature (C.°) series in Clear Lake*

Depth (meters)	May 16, 1942	May 26, 1942	May 31, 1935	June 6, 1935	June 12, 1935	July 10, 1933	Aug. 14, 1933	Sept. 5, 1932
Surface	5.1°C	8.9	10.5	9.4	11.6	21.5	20.1	17.4
5	....	8.9	10.3	9.2	11.1	20.4	20.0	16.3
10	4.9	....	9.3	9.0	10.6	19.2	19.2	16.0
15	....	8.4	8.4	9.1	9.9	12.0	18.3	16.0
20	4.7	6.7	....	8.9	9.5	10.1	12.2	15.7
30	4.6	6.1	7.3	8.6	8.9	9.4	10.2	12.0

Dissolved oxygen was determined with each temperature series. In early summer the surface oxygen was about 7 cubic centimeters per liter—close to saturation. That of the water near bottom varied from 5.2 to 5.9 cubic centimeters—about 70 to 80 percent of saturation. Data for the midsummer period are incomplete. A reduction in the dissolved oxygen of the deep water undoubtedly occurs but the considerable volume of the deep water would probably prevent any serious stagnation. Indirect evidence of oxygen reduction in the deep water is found in the reports that whitefish are very difficult to catch with bottom nets at midsummer.

The water of Clear Lake is moderately alkaline with pH about 8.3 at

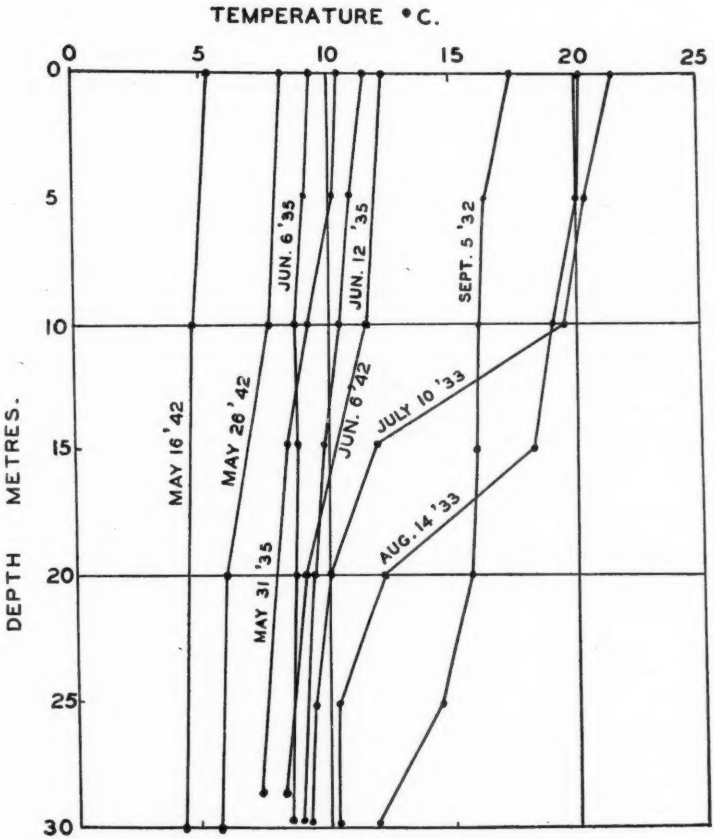

FIGURE 2.—Selected temperature series in Clear Lake

the surface and 7.6 at the bottom. It contains a relatively large quantity of minerals. Analysis for 1932 (by Bajkov) showed 240 p.p.m. of total solids and that for 1942 indicated 274 p.p.m. The arbitrary distinction between fresh and saline waters is often made at 300 p.p.m. Thus Clear Lake lies near the upper limit for fresh waters, a condition resulting from the periods of low water and no outflow. The mineral constituents of the 1942 sample may be listed as follows (all values in p.p.m.):

Total solids at 105°C.	274.0	Silica SiO_2	4.9
Alkalinity as $CaCO_3$	173.7	Iron and alumina	6.0
Bicarbonate HCO_3	211.8	Calcium Ca	13.9
Chloride Cl	2.6	Magnesium Mg	12.4
Sulphate SO_4	47.1	Sodium Na	63.2

It may be noted that this analysis, both in quantity and quality of the salts represented, resembles that of water from Halkett Lake in the Prince Albert Park, another body of water which in many years has no visible outflow (Rawson, 1936). The increase in the total solids of Clear Lake from 240 to 274 p.p.m. in the 10-year period 1932-1942 is not surprising in view of the drought and absence of outflow during that time.

Plankton.—Qualitative studies of the plankton were made by Bajkov in 1932 and by the author in 1935. The dominant forms include: three copepods—*Diaptomus, Epischura,* and *Cyclops;* two cladocerans—*Bosmina* and *Daphnia;* the rotifer *Polyarthra;* the colonial protozoan *Dinobryon;* and three diatoms—*Melosira, Asterionella,* and *Stephanodiscus.* Adequate quantitative data for the plankton have not been obtained. Our own sampling in May and June 1945 suggests a rather poorer plankton than that of Waskesiu and Okanagan Lakes, which were sampled before and after Clear Lake by means of the same equipment. However Bajkov described the plankton as "very rich" and "among the richest of Manitoba lakes." In any case we have no reason to suppose that there is any shortage of plankton as far as maintenance of fish is concerned.

Bottom fauna.—The bottom animals were sampled with a 9-inch Ekman dredge and the material treated by the usual methods of analysis. Data from 26 dredgings are given in Table 2. The bulk of the bottom fauna is made up of chironomid larvae (48 percent), minute clams, *Pisidium* (25 percent), and snails (12 percent). Freshwater shrimps, *Hyalella,* and oligochaete worms were present in moderate numbers and also a few mayfly nymphs, caddis larvae, and leeches. Crayfish, not taken in the quantitative samples, were numerous along the rocky beaches and in the stomachs of whitefish. Shore collections revealed considerable numbers of caddis larvae and mayfly nymphs but, as indicated above, a large proportion of the shoreline is exposed and therefore relatively barren of larger organisms. A great variety of bottom animals was found near shore and in depths down to 10 meters. Between 10 and 20 meters there were no leeches or caddis

TABLE 2.—*Analysis of Clear Lake dredgings*
[See Figure 1 for location of stations]

Dredging number	Depth (meters)	Type of bottom	Chironomid larvae	Mayfly nymphs	Caddis larvae	Oligochaetes	Amphipods (*Hyalella*)	Sphaeriidae (*Pisidium*)	Gastropods	Leeches	Total numbers	Wet weight, grams (mollusc shell deducted)
SID1	5.5	Sand, chara	49	3	5	1	46	52	9	1	166	0.679
D2	9.0	Sand, shells	37	1	....	....	....	36	118	1	193	0.760
D3	22.0	Clay, shells	39	....	....	....	....	24	....	....	63	0.463
D4	23.0	Soft clay	47	1	....	1	....	15	....	....	64	0.554
D5	30.0	Clayey ooze	105	....	....	24	....	....	....	....	130	0.398
D6	30.0	Clayey ooze	61	....	....	8	....	3	....	....	72	0.510
SIID1	1.0	Gravel, sand	24	2	....	6	2	12	....	....	46	0.070
D2	17.0	Soft clay	69	....	....	10	50	25	4	....	158	0.916
D3	31.0	Soft clay	173	....	....	34	....	15	....	....	222	1.473
D4	21.5	Coarse sand	1	....	....	4	....	1	....	....	6	0.005
D5	10.0	Gravel, sand	10	....	....	....	....	2	4	....	16	0.105
D6	2.0	Sand	1	....	....	....	....	....	....	....	1	....
SIIID1	2.0	Stony	23	1	....	10	....	1	....	....	35	0.057
D2	5.5	Sand, chara	75	4	1	6	24	75	14	....	199	0.467
D3	8.5	Gravel, algae	41	....	6	2	3	120	76	2	250	1.560
D4	13.0	Clay ooze	50	3	....	....	....	44	36	....	133	1.040
D5	15.0	Stiff clay	49	....	....	....	9	24	3	....	85	1.594
D6	14.0	Clay ooze	69	5	....	....	6	21	8	....	109	0.950
SIVD1	1.5	Marl, chara	13	1	....	....	6	15	9	....	44	0.200
D2	2.5	Sand	35	7	1	....	12	24	1	....	80	0.378
D3	5.0	Soft clay	15	....	....	....	26	14	5	....	60	0.174
D4	7.0	Clay ooze	44	....	....	9	45	130	40	1	269	1.099
D5	14.0	Clay ooze	20	2	....	....	....	24	6	....	52	0.539
D6	18.0	Clay ooze	58	....	....	8	....	23	....	....	89	0.908
D7	22.0	Ooze, humus	80	1	....	9	....	4	....	....	94	0.595
D8	30.0	Clay ooze	117	....	....	17	....	2	....	....	136	0.544
SVD1	8.0	Gravel	26	....	4	....	2	....	13	2	47	0.338
D2	17.0	Stiff clay	48	2	....	3	....	14	32	....	99	0.986
D3	23.0	Clay ooze	29	1	....	2	....	13	....	....	45	0.111
D4	22.0	Clay ooze	15	....	....	....	....	21	....	....	36	0.099
D5	23.0	Clay ooze	4	....	....	1	....	3	....	....	8	0.014
D6	20.0	Clay ooze	63	2	....	3	....	16	....	....	84	0.515
Totals			1490	36	17	158	231	774	378	7	3091	18.101
Average per dredging			46.5	1.1	0.5	5.0	7.2	24.2	11.8	0.2	96.5	0.566

larvae but snails and mayfly nymphs were still present in moderate numbers. In the deep water, 20 to 30 meters, only three forms were found—chironomid larvae, *Pisidium,* and oligochaete worms.

The average bottom population at all depths was 1,930 per square meter (1,610 per square yard), and its dry weight was 22.6 kilograms per hectare or 20.1 pounds per acre. This is a fairly dense population, considerably heavier than that of the main part of Waskesiu Lake. It is to be expected that Waskesiu which is nearly three times as large as Clear Lake, would have a somewhat less dense bottom fauna.

The abundant supply of bottom food for fish was evident both from the dredgings as recorded above, and from the examination of fish stomachs, especially those of the whitefish.

Fish.—The fish fauna includes at least 13 species. The larger fish were sampled with gangs of gill nets ranging from 1½- to 5½-inch mesh. Nine 24-hour sets were made in 1935 and 16 in 1942. The species taken and the total numbers of each in the 25 sets are listed below:

Common whitefish	*Coregonus clupeaformis*	801
Cisco or tullibee	*Leucichthys* sp.	262
Common sucker	*Catostomus commersonnii*	940
Yellow perch	*Perca flavescens*	898
Pike or jackfish	*Esox lucius*	108

The smaller fish were taken chiefly by seining. More than 50 hauls were made in all parts of the lake with a 30-foot seine of ¼-inch mesh. The specimens are listed in approximate order of abundance as follows:

Spottail minnow	*Notropis hudsonius,* very abundant
Longnose dace	*Rhinichthys cataractae,* common
Brook stickleback	*Eucalia inconstans,* common
Fathead minnow	*Pimephales promelas,* common
Northern millers thumb	*Cottus cognatus,* occasional
Iowa darter	*Poecilichthys exilis,* occasional
Trout perch	*Percopsis omiscomaycus,* few
Johnny darter	*Boleosoma nigrum,* few

The common whitefish is abundant in the lake. A limited commercial fishery was allowed in most of the years from 1935 to 1942. Part of the fishing was in summer and part through the ice in winter. In most years the catch did not exceed 5,000 pounds but in 1942 nearly 35,000 pounds were taken. Commercial fishing would not ordinarily be allowed in National Park waters but it was approved here in order to reduce the numbers of common suckers and yellow perch. The fishermen were required to use some small mesh in order to catch the perch. The whitefish of Clear Lake are of small size and grow relatively slowly. Since their flesh is also heavily infested with cysts of the tapeworm, *Triaenophorus,* the population is of little commercial value. Examination of stomach contents showed that their chief food was chironomid larvae, with considerable quantities of molluscs and crayfish and smaller amounts of aquatic insects and fresh-water

shrimps. The description of the Clear Lake whitefish as a new species, *Coregonus odonoghuei,* by Bajkov (1929) has not been sustained by further examination. Dymond (1943) concluded that it is an ecological form of the widespread species *clupeaformis.*

The cisco found in Clear Lake is a small form, locally known as tullibee but much smaller than the typical tullibee of the prairie lakes. The average weight of specimens taken in the test nets was less than 4 ounces. They are abundant in the lake, more so than the number caught would suggest, since relatively few settings were made in the deep water where ciscoes are most numerous. The food of this species was almost entirely plankton, with a few chironomid larvae. The *Triaenophorus* infestation was heavier in the cisco than in the whitefish.

The common sucker is abundant in the lake; nearly 1,000 were taken in 25 gill-net settings. Most of those taken were less than 10 inches, fork length. The largest were about 16 inches and weighed slightly more than 2 pounds. Although most common near shore it is also taken in the deep water at depths down to 30 meters. This distribution may be related to the absence of the northern sucker (*Catostomus catostomus*) which usually occupies the deeper waters of the lakes in this region. The food of the common sucker was found to consist of about one-third chironomid larvae with considerable quantities of amphipods and some plankton, mayflies, caddis larvae, and molluscs. Suckers were observed spawning along the lake shore a few feet from the water's edge on June 3, 1942. This observation suggests the inadequacy of the few small tributary streams as spawning grounds for this species.

The yellow perch were all of small size, usually less than 8 inches in fork length and 4 ounces in weight. They were found to be spawning at depths of 3 to 10 meters during the last week of May in 1935 and between May 22 and June 7 in 1942. The food of the perch was largely aquatic insects (especially mayfly nymphs) with some minnows and amphipods and also a few snails, crayfish, water-mites, and terrestrial insects.

Northern pike were taken in moderate numbers and practically all were mature and of large size. The scarcity of young pike both in gill-net and seine catches was no doubt related to the lowered water levels which cut off the spawning area known as South Lake and reduced the reedy areas at the northwest. Recent improvement in the water level no doubt will result in an increased propagation of this species. The northern pike had fed extensively on yellow perch, common suckers and ciscoes. A few spottail minnows also were eaten.

Some suggestion of the density of the fish population in Clear Lake may be had from the gill-net catch. The average number of fish caught was higher than that in Waskesiu Lake with similar gangs of nets. However, the average weight per fish in Clear Lake was much less than that in Waskesiu, so the total weight per catch was similar

in the two lakes. The same five species, taken in nets in Clear Lake were found also in Waskesiu but the latter had also the northern sucker, *Catostomus catostomus,* the yellow pickerel or pikeperch, *Stizostedion vitreum,* and the ling or burbot, *Lota maculosa.*

The Suitability of Conditions in Clear Lake for Rainbow Trout

The physical and biological conditions in Clear Lake may be summarized as follows. Its area is 9.5 square miles and its mean depth 43 feet. A moderate thermal stratification occurs in July and August with consequent reduction of the dissolved oxygen in the deeper water. The water is slightly alkaline and the total solid content is 275 p.p.m. This accumulation of salts is the result of interrupted outflow. The plankton, bottom fauna, and fish populations are fairly rich and are composed of the species commonly found in moderately eutrophic lakes in this region.

With this information available, and knowing the conditions under which rainbow trout thrive in lakes of central British Columbia, it was possible to state (1) that the physical conditions such as temperature and oxygen appeared to be suitable for this species and (2) that the food supply including plankton, bottom organisms, and minnows also seemed favorable. Possibly unfavorable conditions were mainly two—the abundance of piscivorous fish and the limitation in size and number of inflowing streams.

The decision in 1935 to attempt stocking Clear Lake with rainbow trout was based on (1) the moderate hope of success provided by the biological survey of the lake, (2) the need to try rainbow trout somewhere in the Prairie Provinces in waters where piscivores were numerous, and (3) the urgent need for a game fish in Clear Lake, the chief resort of Riding Mountain Park.

The Plan and Progress of Stocking

The plan for stocking was essentially that recommended by Mottley in 1935 on the basis of his experience with rainbow trout management in lakes of British Columbia. It was recommended that eggs be obtained from British Columbia and held in troughs and later in rearing ponds until they were at least 2 inches long before planting. The recommended annual planting was 350,000 fish. This heavy planting of about 550 fish per acre was considered desirable in view of the abundance of piscivorous forms in the lake. The procedure was to be continued for 3 years, after which a check-up was to be made to determine whether the plantings had been successful.

The plan was followed in a general way but the number of fish planted was far short of the prescribed number. The first planting of 50,000 fish was made in 1937. In 1938, 35,000 were released; in 1939, 25,000; in 1940, 30,000; in the spring of 1942, 12,000 (carried over-

winter in the rearing ponds); and in the fall of 1942, 13,900. Thus the total planting was 165,000 and the annual average only 28,000 or 8 percent of the number advocated. Various difficulties were encountered in the hatching, transporting, and rearing of these fish. The water in the rearing ponds was too cold for rapid growth and the irregular growth in the absence of sorting resulted in much cannibalism. It will be noted also that planting was carried on for 6 years in spite of the recommendation that a check be made after 3 years and planting discontinued if favorable results were not observed.

Testing for Results of Planting

The first test was made in the period October 19 to November 4, 1940, by H. M. Rogers, Limnologist of the National Parks Bureau. He was unable to capture any rainbow trout in small-mesh gill nets. Two small ones were taken by seining near the rearing ponds. There were reports of rainbow trout taken by anglers but none of these was verified.

A more extensive search was made by the writer in the period May 7 to June 19, 1942. It was first established that there was no spawning run in or near the streams flowing into the lake. Gill nets were then set in all parts and depths of the lake. In 16 gill-net settings 2,700 fish were taken, but no rainbow trout. It may be added also that no trout were captured in commercial fishing operations between December 1942 and March 1943, although about 35,000 fish were caught and some small-mesh nets (2 inches) were used in these operations in order to catch yellow perch. Seining was also carried on in many parts of the lake. In 43 hauls three small rainbow trout were taken. One of these, $3\frac{1}{2}$ inches in length, in the mouth of Bogey Creek had no doubt survived from a previous planting. The other two were smaller and probably belonged to the lot which had been released 2 weeks earlier.

It was thus definitely established that the rainbow trout were not surviving in the lake and it was recommended in 1942 that planting cease.

In July 1945, further gill-netting by Doan took 560 fish and again no rainbow trout were among them.

The Failure of the Rainbow and a New Fish-Culture Plan

It was concluded that the most probable reason for the failure of rainbow trout in Clear Lake is the large number of predatory fish, chiefly the yellow perch. Extensive gill-netting had demonstrated the great abundance of this species and stomach analyses showed that it fed to a considerable extent on fish. The northern pike would also account for some destruction but the numbers of this species are much smaller.

Clear Lake is far from the normal range of the rainbow trout but the earlier examination showed no physical or chemical conditions that should prevent the species from surviving. It is presumed therefore that there exists some biological barrier, probably the yellow perch.

With the failure of the rainbow trout the question as to what action should be taken to improve game fishing arose once more. Lake trout and pikeperch were considered as possible species for introduction but both of these had been planted earlier. In 1927, 100,000 pikeperch were planted and a total of 470,000 lake trout were stocked in the years 1926, 1929, and 1930. An investigation of these plantings revealed that the pikeperch fry were planted as soon as they had absorbed the yolk sac and that the lake trout were planted at a similar stage since they came from the whitefish hatchery at Lake Winnipegosis which had no facilities for holding or feeding trout. Also, in at least one year, planting was carried on while the lake was still covered with ice. It was suggested therefore that these plantings were made under such unfavorable conditions that they did not constitute a fair test for these species.

The physical and biological conditions in the lake, especially its depth, suggested the possibility of planting lake trout. Precise data were lacking as to the extent of oxygen depletion at midsummer but the considerable depth of 30 meters was regarded as reasonable safeguard against extreme stagnation. Thus it was decided to attempt the introduction of lake trout and, to avoid possible repetition of the former planting with immature fry, it was suggested that adult lake trout should be transferred.

Stocking with Lake Trout

Lake trout for stocking Clear Lake were obtained from Clearwater Lake on the Hudson Bay Railway 18 miles west of The Pas. The transfer was arranged through the generous cooperation of the Manitoba Department of Mines and Resources and the Canadian National Railways. In September 1943 the first shipment of 274 adult trout was transferred. In 1944 a second shipment of 296 trout was made, and in 1945 a third of 318. There were no losses in any of these transfers and evidence of their survival in the lake was soon obtained. Four lake trout were taken in gill nets at the west end of the lake in 1943 two days after the planting had been made at the east end. In September 1944 one lake trout was taken by angling and others were seen in shallow water. In July 1945 Doan caught eight trout in seven settings of a gill net which took also 550 other fish, mostly yellow perch and ciscoes. These trout were taken in depths of 90 to 100 feet as might be expected at this season. They weighed from 5 to 8 pounds and were in good condition. They had been feeding on ciscoes.

The survival of the lake trout in Clear Lake is thus established.

There remains the need for determining whether they are spawning successfully in the lake. Dr. V. E. Solman, Limnologist of the National Parks Bureau, plans to make this investigation at the appropriate time.

General Implications of the Clear Lake Experiment

One of the reasons for attempting the introduction of rainbow trout at Clear Lake was to test the response of this species in lakes already populated with piscivorous fish. The failure of rainbow trout to survive even in small numbers in Clear Lake led us to question the utility of planting this species in similar situations elsewhere.

Rainbow trout planting has been urged in lakes of the Prince Albert National Park which, as indicated above, resemble Clear Lake in many respects and lie in the same life and vegetation zone. This introduction was postponed until the results of the Clear Lake experiment were known. It is true that physical conditions in Kingsmere Lake, *e.g.,* inflowing streams, greater depths and lower temperatures, may be more favorable for rainbow trout than those in Clear Lake. Kingsmere, however, has a large population of yellow perch, pike-perch, northern pike, lake trout, and ling, all fish-eating species. It is on the latter grounds that we now recommend against planting rainbow trout in that lake.

In Bow Lake of the Banff National Park, rainbow trout have made almost no progress in spite of heavy and long-continued planting. In this lake the Rocky Mountain whitefish (*Prosopium williamsoni*) and the dolly varden trout (*Salvelinus malma*) are present in considerable numbers. In Pyramid Lake of Jasper Park, conditions are somewhat better in that the dominant species of fish are not piscivorous and are therefore competitors rather than predators. Even in this lake and with the destruction of large numbers of competitor fish, the progress of rainbow trout has been relatively slow. Lake Minnewanka in the Banff Park is much larger but resembles Pyramid Lake in many physical and biological respects. Here, too, the presence of many competitor fish in a lake too large for economic destruction of these competitors appears to be an almost insuperable barrier to establishing rainbow trout. These results added to those obtained at Clear Lake suggest that there is little use in planting rainbow trout in lakes already heavily populated with predator and competitor species.

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PROPAGATION OF THE CREEK CHUB IN PONDS WITH ARTIFICIAL RACEWAYS[1]

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Abstract

Successful spawning of the creek chub (*Semotilus a. atromaculatus*) was achieved in a specially designed raceway. An artificial stream, having a gravel bottom with pools and riffles, was constructed within the basin of a pond in which brood stock were introduced. Spawning activity commenced in late April and terminated in early May. A heavy mortality occurred among the brood stock when the ratio of males was equal to, or greater than that of the females. A better survival was attained by increasing the number of females. The breeding fish had a tendency to concentrate in certain zones of the spawning raceway, and as a result many redds were destroyed in the overworked areas. To offset this condition, thus increasing the efficiency of the raceway, deposited eggs were removed from the beds and successfully cultured in a hatchery by the use of Meehean jars and egg trays. The complete incubation period (fertilized egg to free-swimming fry) was about 25 days at a mean temperature of 55° F. Several rearing ponds were stocked with 8-day-old fry; others with 20-day-old fry. Though the 8-day-old fry were found to tolerate long-distance transporting, they did not survive in any appreciable numbers after introduction into rearing ponds. The stocking of ponds with 20-day-old fry was more successful, for more than 50 percent of the fry survived. Production in ponds where the fish had to rely on a natural food supply was light as compared to that achieved in a pond where artificial feeding was practiced.

Introduction

In recent years, various investigators have given considerable attention to the propagation of bait minnows and forage fishes. They have been prompted by several considerations, among them: (1) regional scarcity of bait minnows in natural waters so great as to induce or even require dealers to propagate their own bait; (2) recognition by fish-culturists of a need for propagating forage minnows to support game fish in hatchery ponds; and (3) realization that it may be desirable, occasionally, to introduce minnows into natural waters.

As a contribution to this problem, studies were initiated in 1940 on the propagation of the creek chub, *Semotilus atromaculatus atromaculatus* Mitchill. Although the experiments are still in progress, enough data have been obtained to warrant publication of results obtained during three seasons from 1944 to 1946.

Accounts of the successful culture of several species of minnows and other forage fishes have been published. Methods for the artificial

[1]Contribution from the Michigan Institute for Fisheries Research. Presented at the Seventy-Sixth Annual Meeting.

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propagation of the creek chub have been described by Hankinson (1910), Marcus (1934), and Clark (1943). Clark made the first large-scale demonstration of the culturing of this species, using artificial raceways and spawning grounds. There were, however, important details lacking from his report. The creek chub's life history has been reported on by Reighard (1910), Hankinson (1910), Leonard (1927), and Greeley (1930).

Preparation of a Spawning Raceway

Observations on the natural spawning habits of the creek chub by the writer together with information in the above references, were of value in designing a spawning raceway. In the first place, it was concluded that the desired production and rate of return from spawning would be dependent upon adequate spawning space for the brood stock. In other words, the raceway had to be large enough to accommodate the brood stock without excessive competition for spawning space. Furthermore, the volume of water and stream gradient had to be sufficient to give a rapid flow, a gravel stream bed was needed for spawning, and some protection for the brood stock against predation by birds was desired.

As a preliminary step in the study a small spawning raceway was constructed in one of the ponds at the State Fish Hatchery at Drayton Plains, Michigan, during the spring of 1944. A gravel-bottom stream 110 feet long by 2 feet wide by 4 inches deep was prepared. The actual construction consisted of digging a trench from the intake pipe toward the outlet, within the basin of the pond, and partially filling this excavation with a 3-inch layer of ¼- to ½-inch screened gravel. At intervals of about 25 feet the stream was widened to form shallow pools which were covered with boards to act as shelters for the breeders. The gradient of the stream from the source to the outlet amounted to 8 inches in the 110 feet, and the incoming flow was regulated at ½ cubic foot per second. Splash boards were installed at the outlet of the pond, raising its water level to a point even with the lower end of the raceway, thus providing a pool for the adults. Operation of this 1944 raceway indicated that various improvements should be made. In 1945 the length of the raceway was increased to 285 feet and the bed widened to 3 feet to provide a greater spawning area. The pools were enlarged somewhat and deepened to provide better cover. The deposition of gravel was increased to 4 inches and the screening size changed to include ¾-inch stones. The flow was increased to ¾ cubic foot per second and the velocity controlled by installing a series of small check dams. In 1946, in further experimentation, the length of the raceway was extended to 300 feet and the width to 5 feet; the depth of the gravel was increased to 5 inches; and the flow of water regulated at 1 cubic foot per second.

As a result of these experiments in raceway construction and opera-

tion, certain features of a satisfactory spawning raceway have been evaluated. A spawning raceway for creek chubs should be constructed within the basin of a pond (Fig. 1) or at a location where a small retaining pool can be formed at the lower end. The purpose of this pool is to provide a haven for the brood stock during inactive periods and to serve as a collecting basin for the newly hatched fry. A raceway capable of furnishing adequate spawning facilities for 500 to 700 fish should be at least 300 feet long and have a minimum width of 5 feet. The flow of water should be at least 1¼ cubic feet per second. Shelters should be provided at intervals of approximately 25 feet along the raceway (upper part of Fig. 2). A suitable type of shelter consists of an offset excavation, joined to the main channel at a point opposite each splash board and covered with any type of weatherproof construction material, such as tarred felt, plywood, or boards. To induce full utilization of the available spawning area by the creek chubs, it is necessary to install splash boards (lower part of Fig. 2) creating pools of slowly moving water between the riffled areas. The height of the splash boards can be altered, thus allowing a control of the velocity and depth of water for any one section. It is desirable to have the stream bed covered with gravel to a depth of 6 inches as studies have shown that egg deposition sometimes occurs nearly to that depth. To allow a good circulation of water through the substratum the gravel should be of ¼- to ¾-inch size, and be free from sand or other fine materials. To protect the breeding fish from predaceous birds, the entire raceway should be covered with some type of netting, or else some sort of a control over these predators should be exercised. In these studies, fish netting supported by stakes (Figure 1) proved to be satisfactory.

Selection of Brood Stock

In the selection of creek chubs suitable for use in an artificial spawning raceway it is desirable to secure a stock of fish in which all females mature at nearly the same time, thus restricting the spawning season to the shortest period possible. The disadvantages arising from an extended season (more than 20 days) are many. The eggs deposited at the onset of the season will have undergone complete incubation and many of the emerging fry will be eaten by the parent fish or will be lost by injury or escape during the operations incidental to removing the adults. Furthermore, finished redds, unguarded, are often reworked by later spawners, thus destroying eggs and developing fry. A principal difficulty encountered in the selection of a brood stock which will meet the above requirements arises from the fact that there is a sex difference in both rate of growth and age of maturity, and also from the fact that age of maturity is dependent to some extent on rate of growth. Greeley (1930) found that the males grow faster and mature at a later age than females. More rapid growth,

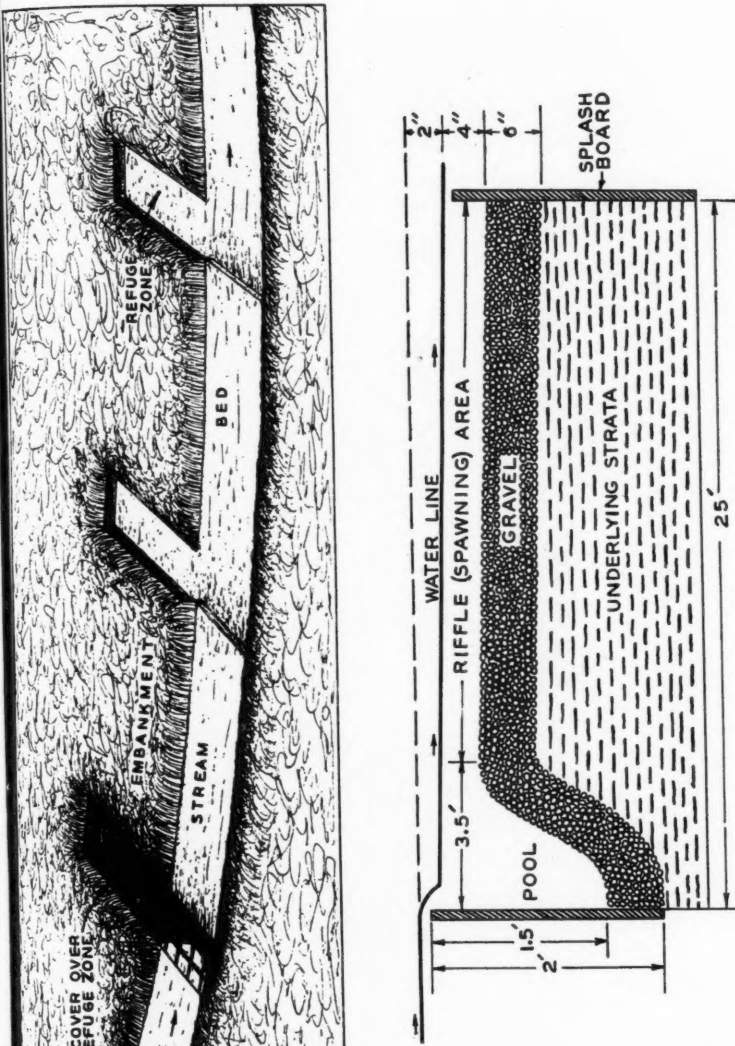

FIGURE 2.—Sketch of creek chub spawning race. Upper: surface view. Lower: longitudinal section of a pool-riffle unit.

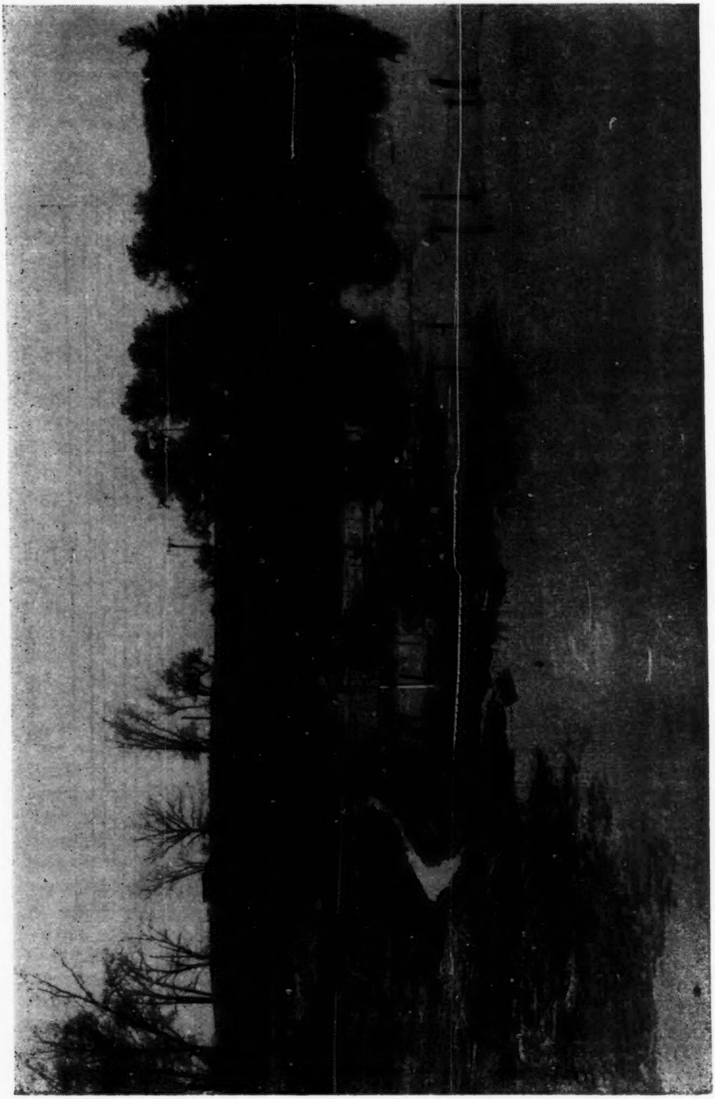

FIGURE 1.—Spawning raceway for creek chubs showing pools, riffles, refuge zones, and lower impoundment. The netting supported by stakes driven in along the stream banks is used to protect the spawning fish from predaceous birds.

later maturity and greater size of mature males have been observed also by the writer. The sex difference in size at maturity makes it difficult to select a brood stock except immediately preceding the spawning season when maturing males can be identified by the presence of nuptial tubercles and females on the basis of their size and distended abdomen. Age alone is not a dependable criterion for the selection of a brood stock, judging from the results of studies by Greeley (1930) and the results of present studies on pond-reared chubs. Greeley found that chubs in natural waters normally mature in their fourth or fifth summer. Presumably the fish studied by Greeley had slow growth. One stock of chubs used in the present experiment comprised pond-reared, fast-growing fish among which some individuals of both sexes were mature in the spring of their second growing season; 25 percent of the males and 50 percent of the females were mature among fish in their third season, and 75 percent of the males and all of the females were mature among fish in their fourth season. In another lot of 120 pond-reared chubs, averaging 5 inches long at one year of age (very fast growth), 75 percent of the individuals of each sex were found to be mature by June 1 of their second season. It would appear that the attainment of a certain minimum size is a more important criterion than age in the selection of mature fish. Selection of a brood stock on the basis of a minimum size of about 5 to 6 inches for females and 6 to 8 inches for males (or 6 to 7 inches for both sexes) among a population with at least moderately fast growth would insure mostly adult fish. However, in a slowly growing population in which the size at maturity might be somewhat less than among rapidly growing fish, the minimum size limit for the selection of a brood stock would of necessity be smaller, or otherwise a preponderance of males would be chosen.

An example of the results from an unselected brood stock may be cited. At the Drayton Plains Hatchery in 1946, the pond was stocked on April 22 with a mixed brood stock of 384 chubs from natural waters and 42 pond-reared chubs. Those of wild stock (4—9½ inches) were larger than the pond-reared 2-year-olds (3—6 inches), and presumably were much older. In the spawning raceway, all of the larger females (mostly wild stock) had spawned by May 2, while most of the smaller females spawned during the period May 2 to 16 and later. The entire spawning season had extended over a period of 25 days, and the earlier fry were leaving the redds before spawning was completed. Also, there was considerable reworking of completed redds during spawning in the latter part of the season.

In order to utilize efficiently the facilities of a spawning raceway, a prescribed number of breeders per unit of area is needed. Varying the rate of stocking over the 3-year period and determinations on the fecundity of females and on the concentration of eggs in redds of known area, have given some indication of the desirable number of breeders. On the average an individual male creek chub requires an

FIGURE 1.—Spawning raceway for creek chubs showing pools, riffles, refuge zones, and lower impoundment. The netting supported by stakes driven in along the stream banks is used to protect the spawning fish from predaceous birds.

area one foot wide and several feet long for nesting space; upon completion the redd is about 8 inches wide and 2 to 6 feet long. An average of several counts on the number of eggs screened from completed redds gave approximately 2,500 eggs per running foot. Egg counts on female creek chubs averaged approximately 3,500 for females averaging 5 inches in length, and 5,000 for 6-inch chubs. On the basis of these findings, the potential egg production of the brood stocks used in 1944 to 1946 is compared with the capacity of the raceway for the different seasons, in Table 1. It is shown that theoretically the raceway was overstocked in 1944 and understocked in 1945 and 1946. Unfortunately the true capacity of a raceway cannot be determined on such simple grounds. Attention should be called especially to a difficulty that is commonly encountered and is accentuated by a protracted spawning season. The chubs do not disperse their redds efficiently over the area available, but the late spawners rework and destroy earlier redds. In 1944, though the raceway was potentially overstocked from the standpoint of egg capacity, the breeders used only a portion of the available spawning area. In 1945, only about 35 percent of available area was utilized, and a still smaller percentage in 1946 (Table 3). In that year through intensive observations it was found that there was a tendency for male chubs to concentrate in certain zones of the spawning raceway and as a result many redds were reworked. From outward appearance the physical features of the entire raceway were more or less identical and as yet no reason can be found to explain this concentration in certain zones. It is apparent that there still remains the problem of determining more exactly the spawning requirements of the creek chub. Once this has been accomplished and a satisfactory raceway designed in which the entire available spawning area is uniformly utilized by the brood stock, it

TABLE 1.—*Stocking rate of adult creek chubs for a 3-year period and estimated footage of spawning raceway needed in comparison with that available*

Year	Stocking rate		Average fecundity of females[1]	Estimated total egg production	Raceway dimensions	
	Males	Females			Square feet needed for egg deposition[2]	Square feet available[3]
1944	83	101	5,000	505,000	202	123
1945	60	90	5,000	450,000	180	506
1946	164	262	3,500	917,000	367	988

[1]The average fecundity for females (16 ovary counts) ranging between 3 and 7 inches was 3,500 and for 4- to 8-inch fish (12 ovary counts), 5,000.
[2]Calculated on a basis of an average of 2,500 eggs deposited per running foot.
[3]Pools, refuge zones, and stream-bank margins have been deducted from total area.

will then be possible to calculate stocking rates satisfactorily. Pending the results of more critical studies, the stocking rates used during the three years at the Drayton Plains pond (Table 1) may be regarded as representing the minimum and maximum of a suitable rate of stocking for the size of raceway indicated. The average size of the females should be taken into consideration because of the difference

in fecundity. A ratio of about two males to three females is recommended to minimize the conflict among males on the spawning grounds.

Observations on the Spawning Activity of Creek Chubs

In Michigan, the spawning season of the creek chub commences about mid-April in streams along the Michigan-Ohio border and extends to late June in waters of the Upper Peninsula. In a single locality the length of the season is about 25 days. At Drayton Plains the brood stock of chubs each year was introduced into the raceway pond shortly before the time of spawning in local streams. In Table 2 are the spawning dates for the raceway fish over a 3-year period showing the length of the season and the prevailing water temperature at the onset of reproductive activity. The extended season in 1945, 12 days longer than either of the other two years, can be explained in part by the presence of abnormal weather. Unseasonably high water temperatures in early April caused a flurry of activity which soon subsided with lowering temperatures, and as a result a 2-week inactive period was encountered.

Table 2.—*Extent of spawning season of creek chubs in a prepared raceway and prevailing water temperatures (°F.), for a 3-year period*

Stocking date	Water temperature	First spawning activity: Date	First spawning activity: Water temperature	Date of termination of spawning[1]	Total length of season
April 24, 1944	46°	April 29, 1944	55°	May 19, 1944	25
April 11, 1945	61°	April 16, 1945	61°	May 27, 1945	41
April 17, 1946	50°	April 22, 1946	56°	May 21, 1946	29

[1]The date recorded is approximate (accurate within 2 days)

In the raceway, spawning activity was more concentrated in the lower sections during the first few days, and the activity was gradually extended upstream as the season progressed. Data on the distribution of redds in the raceway throughout the season are presented in

Table 3.—*Addition of the new creek-chub redds in raceway sections over a 19-day period*

[The sections are numbered consecutively with No. 1 at the upstream end]

Date of observation	Number of new redds in raceway sections: [1]1	2	3	4	5	6	7	8	9	10	11	12	[2]13	Total number redds to date
April 22, 1946	1	0	1	3	0	2	1	0	4	2	7	1	0	22
April 23, 1946	0	1	0	1	0	1	1	1	1	1	1	0	1	31
April 25, 1946	0	2	3	3	1	0	6	2	3	0	2	0	1	53
May 4, 1946	0	0	0	2	0	2	4	0	5	2	2	0	0	71
May 10, 1946	0	0	1	5	6	2	2	0	1	0	2	3	0	93
Total number of redds per section	1	3	5	14	7	7	14	3	14	5	14	4	2	....

[1]Inlet section, about one-half length of others.
[2]Partial section below number 12, junction of stream and pond

Table 3. On the first observation date, April 22, 1946, about 63 percent of the redds were found in the lower one-third of the raceway, whereas by April 25 this figure was reduced to 45 percent, indicating that relatively more males were establishing redds in upper sections. By the end of the season 4 of the 13 sections (4, 7, 9 and 11), comprising about one-third of the total area, contained 56 redds or 60 percent of the total.

Both sexes took part in the first upstream movement of the breeders from the pond; the males were extremely active on the riffle zones and the females darted about in secluded areas. During the initial phase it was noted that spawning activity started about mid-morning and terminated an hour or so before dusk. At the height of the season, however, the fish were engaged in nesting operations day and night, stopping only when water temperatures fell below 51°F. The lowering of the water temperature not only curtailed reproductive activity, but also brought about a downstream movement of the brood stock to the pool below. Periodic observations of the adults over the entire spawning season revealed that some fish were present in the pool at all times. The presence of many spent females in the pool indicates that some, if not all, of them leave the race after spawning.

Within a few days after the end of each spawning season, all surviving adults were recovered from the pond and raceway. In each year there was a large loss of both sexes. In 1944, out of 184 fish introduced, only 65 survived—16 males and 49 females. The mortality rates were 80 and 50 percent respectively. During the 1945 season the combined mortality was somewhat higher—78 percent of the males and 62 percent of the females. In 1946, the mortality was much lighter than for either of the two former years—40 percent of the males and 15 percent of the females. It is believed that the exceptionally high mortality recorded for 1945 was in part due to the predations of the great blue heron, since the raceway was not screened that year and herons were common. However, for 1944 and 1946 it is definitely known that predaceous birds were not a contributing factor because the raceways were well screened. The difference between the mortalities of 1944 and 1946 might have been due to the difference in growth history:—the 1944 breeders were large, fast-growing, pond-reared chubs, and the 1946 fish were smaller, presumably more slowly growing, wild chubs. It has been noted by numerous investigators that fast-growing fish tend to have a relatively short life span.

Collecting of Eggs and Incubation Period

During 1944 and 1945 studies of the mortality and incubation of chub eggs were limited to the examination of several redds. By screening the eggs from portions of redds, it was found that a higher mortality occurred in nests located in the quieter waters. Since it was observed that sediment had accumulated more over the nests in quieter

water, it is possible that the mortality was caused by suffocation. During the season of 1945 a protracted incubation period, brought about by low average water temperatures, a considerable deposit of silt accumulated over all the redds, even those in fast water. There was an excessive mortality among the newly hatched fry in all redds, again presumably as the result of suffocation.

In view of the observed loss of eggs in redds during 1944 and 1945, a variation in the procedure was instituted in 1946. Certain redds were opened, the eggs removed, taken to a fish hatchery, and incubated. The purpose was twofold: first, to seek a means of greater production of fry by the progressive removal of a portion of the eggs from over-crowded nesting areas (Table 3); and second, to secure pertinent data on the incubation period. As a means of collecting eggs a three-sided, 12-inch-square, screen box, was placed immediately below a nest. By sifting the gravel through the hands, the eggs were washed free and collected in the trap below. It required several successive washings to insure that all of the eggs were removed from a particular redd. The loss of eggs (by crushing or failure to be trapped) during removal in this manner was estimated at not more than 25 percent.

A total of 98 fluid ounces of eggs (115,000 to 130,000 per quart) was removed from redds in the above manner—31 ounces on April 23, 35 ounces on April 25, and 32 ounces on April 29. These eggs were placed in hatchery jars on each occasion, and the incubation period studied. It was found that creek chub eggs could be incubated to the eyed stage in hatchery jars, but could not be hatched successfully because the heavy fry did not escape with the running water. If left in the jars the fry had a tendency to settle and accumulate near the bottom and die as a result of mechanical injury. At the eyed stage the eggs were transferred to screened trays in standard hatchery troughs for the remainder of their development. This jar-tray method proved to be successful (Table 4). The use of trays alone for the entire incubation was attempted but was found to be less satisfactory than jars for early development, because of the difficulty of picking dead eggs from trays. The greatest egg mortality was encountered within the first 6 days of development. In the jars the dead eggs accu-

TABLE 4.—*Percentage of hatch of creek chub eggs collected from nests and incubated in the hatchery*

Egg collection		Water temperature	Incubation period (hours)			Ounces[2] of fry	Percent-age of
Date	Ounces[1]	(°F.)	Jar	Tray	Total	produced	hatch
April 23, 1946	31	55	147	94	241	14.5	67
April 25, 1946	35	54	178	81	259	17.4	71
April 29, 1946	32	56	154	86	240	14.0	63

[1]The average number of eggs per fluid ounce was 3,750

[2]The average number of fry per fluid ounce was 5,400

mulated at the surface of the egg mass and could be siphoned off. From the original 98 ounces of eggs (3,750 per ounce) approximately 46 ounces of fry (5,400 per ounce) were produced, representing a hatch of about 67 percent. The average incubation period at a mean temperature of 55°F. was 10 days, 6½ hours.

The sac fry upon hatching pass through the 14- by 18-mesh screen to the bottom of the trough and undergo further development there for a period of 12 to 16 days. At hatching the fry are gold-colored and the eyes are without any marked pigmentation. Within 2 to 3 days, the fry take on a dark, orange color, and the eyes become very conspicuous. Within another 3 days, dark lateral bands of melanophores appear on the sides of the body. Within 12 days after hatching the fry are able to maintain a normal position, can swim feebly, and support themselves in a weak current. By 16 days the yolk sac is absorbed and the fry are ready to take food. It was noted during these studies that the fry had a tendency to concentrate in shaded areas or about any dark object placed in the trough (negatively phototropic). It was discovered further that they react positively to a current (positively rheotropic)and will collect in large masses. One such large concentration of fry was followed by an abnormal mortality. Thereafter, excessive concentrations were dispersed by feathering, or prevented by control of water currents and reduction in the number of fry in the troughs.

For a comparison with the incubation period of creek chub eggs reared by the jar-tray method, observations were made on eggs in the raceway redds. Certain redds were examined periodically throughout the spawning season. The water temperature in the spawning raceway averaged about 1° to 2° F. higher than that in the jar, and the range of variation was found to be greater. In the hatchery, the lowest temperature recorded was 50° and the highest 59°, while in the stream the lowest was 49° and the highest 64°. The rate of development of the eggs up to hatching was about the same in redds and jars. However, development of fry must have been somewhat faster in the redds, for free-swimming fry were observed in the raceway within 20 days after the first spawning, whereas it required from 22 to 26 days to reach a comparable stage in jar-tray rearing.

In some redds dark, pigmented fry were found still imbedded in the gravel at depths up to 3 inches. Upon liberation, these fry quickly swam away in a normal manner. Apparently the fry remain in the beds until they are well developed.

For a comparative study of the viability of naturally and artificially spawned eggs, 47 ounces of creek chub eggs were obtained from 14 redds in Paint Creek, Oakland County, Michigan on April 26, 1946, and taken to the hatchery for incubation. At the time of collection, some of these eggs showed no signs of development and others had progressed to the eyed stage. Many of the eggs were hatching 2 days later, while others required 6 to 8 days. From the 47 ounces of eggs

only 13.8 ounces of fry were produced, representing a hatch of about 42 percent. The low rate of hatching of the Paint Creek eggs, as compared to the 67 percent hatch of eggs from raceway redds, can be attributed partly to the spread in time of hatching (discussed below). The spread in time of hatching among individual lots of eggs was found to be an objectionable feature in the jar-tray method, because of the need for transferring eggs to trays at the eyed stage. Many fry not removed are destroyed by mechanical action in the jars (see above). It is desirable therefore to have individual lots of eggs of uniform age. The experience with the eggs from Paint Creek indicated that it normally would be more difficult to obtain eggs of uniform age from natural streams where the history of individual redds is not observed. Other contributing factors to the high mortality of naturally spawned eggs might have been the sensitivity of the eggs at some specific stage in development to changes in water temperature, to handling, or to jarring in transit. It is a well-known fact that eggs of salmonids can be handled safely either when "green" or at the eyed stage, but that there is a long intervening period when the eggs are highly sensitive to jarring. It is probably safe to assume that the same is true of creek chub eggs, although it has not been demonstrated. It would seem desirable therefore to collect the eggs from nests shortly after deposition. In the present studies at the Drayton Plains raceway the eggs were removed within 24 hours, which interval proved to be satisfactory.

Transfer of Fry

During the 1946 studies it was found that 4- to 8-day-old sac fry could be handled safely and transported for long distances. On May 7, 1946, 95,000 sac fry (volumetric measurement, 180 fry per cubic centimeter) were carried in a light truck in 10-gallon fish cans at the rate of 12,000 per can for a distance of 110 miles without significant loss. This successful operation was repeated again on May 13, at which time 115,000 fry were moved the same distance. Each of these trips required about 3½ hours to complete, and the water was not changed en route. The sac fry, not advanced enough for free swimming, settled to the bottom when placed in the can, and remained in that position during transit.

Some transfers of advanced fry (free-swimming for 8 to 12 days) were made from the raceway pond to other ponds at the Drayton Plains Hatchery. These fry were collected by bobbinet seine and transported in pails and fish cans. A total of 33,000 fry was handled without appreciable loss. In another transfer, 20,000 fry of this age were transported by truck in 10-gallon cans for a distance of 60 miles without significant loss. It is concluded from these results that advanced fry can survive handling and transportation over long distances.

Stocking of Fry

Some information was obtained by studies during 1946 on the relationship between rate of stocking and age of stocked fry on the one hand and the rate of survival, and rate of growth on the other (Table 5). Eight ponds at the Hastings State Fish Hatchery and two ponds at the Drayton Plains State Fish Hatchery were stocked with 8-day-old and 20-day-old creek chub fry, respectively. The 8-day-old fry (not free swimming) were placed on screen trays located in one foot of water. The 20-day-old fry (free swimming) were simply liberated into the ponds. During September all ponds were drained. The fish were removed, counted, weighed and individual lengths were obtained from representative samples.

The ponds stocked with 20-day-old fry gave much higher rates of survival (51 and 73 percent) than those stocked with 8-day-old fry (17 percent and less). In the series of experiments at Hastings where rates of stocking were varied from 10,000 to 44,000 per acre, the percentage rate of survival tended to be higher in those ponds stocked at the higher rates. This result is contrary to that ordinarily obtained from fry planting. The great variation among the three ponds which were stocked at 25,000 per acre indicates, however, that rate of survival was determined mostly by factors other than rate of stocking. Rapid growth was strikingly related to low concentrations of chubs in this series of experiments. In Ponds 5, 12, 7, and 11 where production was extremely low, the fish in a 135-day growing season attained an average length of more than 4 inches; in ponds 2, 8, 10, and 6, where production was moderate, the fish in 128 days attained average lengths between 3 and 4 inches; whereas in ponds 3 and 4 where relative high production occurred, the fish in a 115-day season grew to an average length of 2½ inches. It is believed that the differences in growth among the three groups of fish can be attributed to the amount of food available per individual. Since the fish in all of the ponds had to rely upon food from natural sources it is assumed that the fish in those ponds experiencing a light survival and a rapid growth had an abundant supply of food. If the assumption is correct that food is a major limiting factor in growth of pond-reared chubs, then artificial feeding with the correct diet might be expected to give a greater production of larger fish. In a separate experiment at Drayton Plains, there was a marked indication of increased production from artificial feeding. A 1.8-acre pond produced 58,000 chubs of 2¾ inches average length in a 115-day growing season; 800 pounds of food were used and the 58,000 chubs, when recovered, weighed 328 pounds. The rate of feeding was relatively low as compared to that employed by Clark (1943) in the propagation of creek chubs. In a 1941 experiment a total of 952 pounds of food was used to produce 11,000 chubs weighing 137 pounds in a 1/12-acre pond, and in 1942, 776 pounds of food were used to produce 9,000 chubs in a 1/7-acre pond.

TABLE 5.—*Results from stocking ponds with creek chub fry at different ages and rates*
[Ponds 3 and 4 were at the Drayton Plains Hatchery; the remaining ponds were at the Hastings Hatchery]

Pond No.	Area (acres)	Stocking rate		Maximum age of fry (days)	Date of introduction	Date of removal	Total number removed	Average length (inches)	Percentage survival
		Per acre	Per pond						
5	2.11	10,000	21,100	8	May 7, 1946	Sept. 19, 1946	421	4.82	2.0
12	1.50	10,000	15,000	8	do.	do.	219	4.26	1.5
3	0.46	38,700	17,800	20	June 3, 1946	Sept. 26, 1946	9,158	2.53	51.4
4	0.48	32,000	15,400	20	do.	do.	11,224	2.47	72.9
7	1.11	25,000	27,750	8	May 7, 1946	Sept. 19, 1946	342	4.37	1.2
11	1.25	25,000	31,250	8	do.	do.	84	4.19	0.3
2	1.02	25,000	25,500	8	May 14, 1946	do.	4,500	3.10	17.6
8	0.98	35,000	34,300	8	do.	do.	1,312	3.70	3.8
10	1.00	35,000	35,000	8	do.	Sept. 20, 1946	2,880	3.72	8.2
6	0.56	44,000	24,640	8	do.	do.	3,850	3.92	15.6

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APPENDICES

AMERICAN FISHERIES SOCIETY

Special Publication No. 1

A LIST OF COMMON AND SCIENTIFIC NAMES OF THE BETTER KNOWN FISHES OF THE UNITED STATES AND CANADA

Report of the Committee on Common and Scientific Names of Fishes, Presented at the Seventy-Seventh Annual Meeting, Denver, Colorado, September 10-12, 1947

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Ann Arbor, Michigan
1948

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INTRODUCTION

The Committee on Common and Scientific Names of Fishes was originally appointed as the result of a resolution adopted in 1933 to form a permanent committee, "to prepare and submit for publication a list of common names of fishes corresponding to the accepted scientific names."

After a reorganization in 1938 actual work was started on the project. The following rules of procedure were adopted by vote of the committee members:

1. Only one common name to be accepted for each fish.
2. Any common name receiving a two-thirds vote of the committee members to be accepted.
3. The word "Common" in connection with a fish's name to be avoided wherever possible.
4. The common names to be simplified, omitting hyphens, suffixes, etc., except where they had a special meaning.
5. Geographical names to be eliminated except where a restricted range made them appropriate.
6. The entire list to be completed before submission to the Society.

As it was felt that a two-thirds vote of seven committee members was not adequate to cover the entire area under discussion it was decided to consult with a number of other workers in various sections of the United States and Canada. At one time or another votes were taken from a total of 26 persons engaged in some form of fishery work. A list of the collaborators is given later in this report.

There are several groups applying common names to fishes. These include: sport fishermen; commercial fishermen; fish-culturists; and scientific workers. Often each group has a different name for the same fish. This confusion is complicated further by purely local names applied to the same fish in different geographical areas, and it is noticeable that the differences hardest to arbitrate are those between adjacent areas.

Another source of confusion that the Committee attempted to correct was the use of the same common name in widely separated areas for two or more entirely dissimilar fishes.

All of the workers agreed in principle that the common names in use for many fishes are inappropriate; in practice, however, they showed a surprising unanimity in being perfectly willing to change the names of such fishes provided they were not found in the workers' particular field of operations.

Three general votes were taken and a number of suggestions were received from experts on particular groups of fishes. Despite the presentation of various arguments and opinions with each succeeding list that was sent out, there was very little change between the final vote received and the original opinions expressed.

When it appeared this work might go on indefinitely, the Executive Committee of this Society requested the Chairman of this Committee to present at the last convention a list containing those names on which a general agreement had been reached. At that time there

were only some 40 names which had not received at least a two-thirds vote. The Chairman requested one year additional time during which these names could be submitted once more to the members of the official committee, and virtually promised that the completed list would be submitted at the convention in Denver. The list that is submitted herewith represents the consensus of opinion of all the workers cooperating in the project.

In all, 605 fishes were considered for the list. Of these, 35 were eliminated as not of sufficient interest to be included. Of the remaining 570, 245, or 43 percent, were the unanimous choice of all those voting; 291, or 50 percent, were approved by at least a two-thirds vote; the remaining 34 names are on the list by virtue of a majority vote of the members of the committee. Thus, only 7 percent have received less than a two-thirds vote.

It is probable that this list as submitted does not meet with the complete approval of any one member of the Committee, including the Chairman. There are still a number of names that are inappropriate but it is apparent from the vote received that general popular acceptance was considered more important than proper usage.

The word "Common" has been eliminated in all names except where no other differentiating adjective was available. The spelling of most of the common names has been made to agree with popular usage rather than the form used in text books. Also, an effort has been made to eliminate all unnecessary hyphens and suffixes. The few geographical names that have been retained in the list comply with Rule 5, mentioned above.

If the names herein advocated are generally used by members of the Society it may be possible, at a later date, for another committee to attack this problem again and eliminate some of the remaining inconsistent and inappropriate names. This list consists of three parts.

1. A list in systematic order of 570 fishes with one common name for each fish (with two exceptions) and the generally accepted scientific name.
2. An index of all the common names considered by the committee. Those names recommended in the main list are printed in capital letters. Secondary and rejected names are printed in lower case.
3. An index of the scientific names used in the main list.

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PART I. ACCEPTED COMMON NAME, OCCURRENCE, AND SCIENTIFIC NAME

Common Name	Occurrence[1]	Scientific Name
HAGFISHES		
1 ATLANTIC HAGFISH	A	*Myxine glutinosa*
2 PACIFIC HAGFISH	P	*Polistotrema stoutii*
LAMPREYS		
3 SEA LAMPREY	A-F	*Petromyzon marinus*
4 SILVER LAMPREY	F	*Ichthyomyzon unicuspis*
5 CHESTNUT LAMPREY	F	*Ichthyomyzon castaneus*
6 PACIFIC LAMPREY	P-F	*Entosphenus tridentatus*
7 AMERICAN BROOK LAMPREY	F	*Entosphenus lamottenii*
8 WESTERN BROOK LAMPREY	P-F	*Lampetra planeri*
SHARKS		
9 BULLHEAD SHARK	P	*Gyropleurodus francisci*
10 ATLANTIC MUD SHARK	A	*Hexanchus griseus*
11 PACIFIC MUD SHARK	P	*Hexanchus corinus*
12 SPOTTED COW SHARK	P	*Notorynchus maculatus*
13 SWELL SHARK	P	*Cephaloscyllium uter*
14 BROWN SHARK	P	*Apristurus brunneus*
15 NURSE SHARK	A	*Ginglymostoma cirratum*
16 ATLANTIC SMOOTH DOGFISH	A	*Mustelus canis*
17 CALIFORNIA SMOOTH DOGFISH	P	*Mustelus californicus*
18 LEOPARD SHARK	P	*Triakis semifasciata*
19 SOUPFIN SHARK	P	*Galeorhinus zyopterus*
20 TIGER SHARK	A	*Galeocerdo arcticus*
21 SHARPNOSE SHARK	A	*Scoliodon terrae-novae*
22 DUSKY SHARK	A	*Carcharias obscurus*
23 BLACKTIP SHARK	A	*Carcharias limbatus*
24 SANDBAR SHARK	A	*Carcharias milberti*
25 BLACKNOSE SHARK	A	*Carcharias acronotus*
26 BULL SHARK	A	*Carcharias platyodon*
27 LEMON SHARK	A	*Hypoprion brevirostris*
28 GREAT BLUE SHARK	A-P	*Prionace glauca*
29 HAMMERHEAD SHARK	A-P	*Sphyrna zygaena*
30 BONNETNOSE SHARK	A	*Sphyrna tiburo*
31 WHALE SHARK	A-P	*Rhincodon typus*
32 THRESHER SHARK	A-P	*Alopias vulpinus*
33 SAND SHARK	A	*Odontaspis littoralis*
34 PORBEAGLE	A	*Lamna nasus*

[1] A = Atlantic; P = Pacific; F = freshwater

Common Name	Occurrence	Scientific Name
SHARKS (Cont.)		
35 MACKEREL SHARK	A	*Isurus tigris*
36 BONITO SHARK	P	*Isurus glaucus*
37 GREAT WHITE SHARK	A-P	*Carcharodon carcharias*
38 BASKING SHARK	A-P	*Cetorhinus maximus*
39 ATLANTIC SPINY DOGFISH	A	*Squalus acanthias*
40 PACIFIC SPINY DOGFISH	P	*Squalus suckleyi*
41 SLEEPER SHARK	A-P	*Somniosus microcephalus*
ANGEL SHARKS		
42 ATLANTIC MONKFISH	A	*Squatina squatina*
43 PACIFIC MONKFISH	P	*Squatina californica*
SAWFISHES		
44 SAWFISH	A	*Pristis pectinatus*
GUITARFISHES		
45 ATLANTIC GUITARFISH	A	*Rhinobatos lentiginosus*
46 CALIFORNIA GUITARFISH	P	*Rhinobatos productus*
SKATES		
47 BARNDOOR SKATE	A	*Raja stabuliforis*
48 ATLANTIC PRICKLY SKATE	A	*Raja scabrata*
49 PACIFIC PRICKLY SKATE	P	*Raja stellulata*
50 CLEARNOSE SKATE	A	*Raja eglanteria*
51 LITTLE SKATE	A	*Raja erinacea*
52 WINTER SKATE	A	*Raja diaphanes*
53 SMOOTH SKATE	A	*Raja senta*
54 LONGNOSE SKATE	P	*Raja rhina*
55 BLACK SKATE	P	*Raja kincaidii*
56 BIG SKATE	P	*Raja binoculata*
57 CALIFORNIA SKATE	P	*Raja inornata*
RAYS		
58 ATLANTIC TORPEDO	A	*Tetranarce occidentalis*
59 PACIFIC TORPEDO	P	*Tetranarce californica*
60 ATLANTIC STINGRAY	A	*Dasyatis*, species
61 BUTTERFLY RAY	A	*Pteroplatea*, species
62 ROUND STINGRAY	P	*Urobatis halleri*
63 SPOTTED EAGLERAY	A	*Aëtobatus narinari*
64 BAT STINGRAY	P	*Aëtobatus californicus*
65 BULLNOSE RAY	A	*Myliobatus freminvillii*
66 COWNOSE RAY	A	*Rhinoptera quadriloba*
67 DEVIL RAY	A-P	*Manta birostris*
RATFISHES		
68 CHIMAERA	A	*Chimaera affinis*
69 RATFISH	P	*Hydrolagus colliei*

Common Name	Occurrence	Scientific Name
STURGEONS		
70 WHITE STURGEON	P-F	*Acipenser transmontanus*
71 ATLANTIC STURGEON	A-F	*Acipenser oxyrhynchus*
72 SHORTNOSE STURGEON	A-F	*Acipenser brevirostris*
73 GREEN STURGEON	P-F	*Acipenser acutirostris*
74 LAKE STURGEON	F	*Acipenser fulvescens*
75 SHOVELNOSE STURGEON	F	*Scaphirhynchus platorynchus*
PADDLEFISH		
76 PADDLEFISH	F	*Polyodon spathula*
GARS		
77 LONGNOSE GAR	F	*Lepisosteus osseus*
78 SPOTTED GAR	F	*Lepisosteus productus*
79 SHORTNOSE GAR	F	*Lepisosteus platostomus*
80 ALLIGATOR GAR	F	*Lepisosteus spatula*
BOWFINS		
81 BOWFIN	F	*Amia calva*
TARPONS		
82 BIGEYE HERRING	A	*Elops saurus*
83 TARPON	A	*Tarpon atlanticus*
LADYFISHES		
84 BONEFISH	A	*Albula vulpes*
MOONEYES		
85 MOONEYE	F	*Hiodon tergisus*
86 GOLDEYE	F	*Amphiodon alosoides*
HERRINGS		
87 ATLANTIC HERRING	A	*Clupea harengus*
88 PACIFIC HERRING	P	*Clupea pallasii*
89 ALEWIFE	A-F	*Pomolobus pseudoharengus*
90 HICKORY SHAD	A	*Pomolobus mediocris*
91 SKIPJACK	F	*Pomolobus chrysochloris*
92 GLUT HERRING	A	*Pomolobus aestivalis*
93 AMERICAN SHAD	A-F-P	*Alosa sapidissima*
94 PILCHARD / CALIFORNIA SARDINE } equal force	P	*Sardinops caerulea*
95 MENHADEN	A	*Brevoortia tyrannus*
96 GIZZARD SHAD	A-F	*Dorosoma cepedianum*
ROUND HERRINGS		
97 ATLANTIC ROUND HERRING	A	*Etrumeus sadina*
98 PACIFIC ROUND HERRING	P	*Etrumeus micropus*

Common Name	Occurrence	Scientific Name
ANCHOVIES		
99 PACIFIC ANCHOVY	P	*Engraulis mordax*
100 DEEPBODY ANCHOVY	P	*Anchoa compressa*
101 ANCHOVY	A	*Anchoviella* and *Anchoa,* species
SALMON		
102 PINK SALMON	P-F	*Oncorhynchus gorbuscha*
103 CHUM SALMON	P-F	*Oncorhynchus keta*
104 SILVER SALMON	P-F	*Oncorhynchus kisutch*
105 RED SALMON	P-F	*Oncorhynchus nerka nerka*
106 KOKANEE	F	*Oncorhynchus nerka kennerlyi*
107 KING SALMON	P-F	*Oncorhynchus tshawytscha*
108 ATLANTIC SALMON	A-F	*Salmo salar salar*
109 SEBAGO SALMON	F	*Salmo salar sebago*
TROUT		
110 CUTTHROAT TROUT	P-F	*Salmo clarkii*
111 RAINBOW TROUT fresh-water form; STEELHEAD TROUT sea run of above	P-F	*Salmo gairdnerii*
112 GOLDEN TROUT	F	*Salmo agua-bonita*
113 BROWN TROUT	A-F	*Salmo trutta*
114 LAKE TROUT	F	*Cristivomer namaycush*
115 EASTERN BROOK TROUT	F	*Salvelinus fontinalis*
116 SUNAPEE TROUT	F	*Salvelinus aureolus*
117 ARCTIC CHARR	F	*Salvelinus alpinus*
118 DOLLY VARDEN	F	*Salvelinus malma spectabilis*
WHITEFISHES		
119 INCONNU	F	*Stenodus leucichthys mackenzii*
120 SHALLOWWATER CISCO	F	*Leucichthys artedi*
121 DEEPWATER CISCO	F	*Leucichthys johannae*
122 LONGJAW CISCO	F	*Leucichthys alpenae*
123 SHORTJAW CISCO	F	*Leucichthys zenithicus*
124 SHORTNOSE CISCO	F	*Leucichthys reighardi*
125 BLACKFIN CISCO	F	*Leucichthys nigripinnis*
126 KIYI	F	*Leucichthys kiyi*
127 BLOATER	F	*Leucichthys hoyi*
128 LAKE WHITEFISH	F	*Coregonus clupeaformis*
129 ROUND WHITEFISH	F	*Prosopium cylindraceum quadrilaterale*
130 MOUNTAIN WHITEFISH	F	*Prosopium williamsoni*
GRAYLINGS		
131 AMERICAN GRAYLING	F	*Thymallus signifer*

Common Name	Occurrence	Scientific Name
SMELTS		
132 CAPELIN	A	*Mallotus villosus*
133 EULACHON	P	*Thaleichthys pacificus*
134 AMERICAN SMELT	A-F	*Osmerus mordax*
135 SURF SMELT	P	*Hypomesus pretiosus*
EELS and MORAYS		
136 AMERICAN EEL	A-F	*Anguilla bostoniensis*
137 CONGER EEL	A	*Conger oceanicus*
138 CALIFORNIA MORAY	P	*Gymnothorax mordax*
139 SPECKLED MORAY	A	*Gymnothorax moringa*
140 GREEN MORAY	A	*Gymnothorax funebris*
SUCKERS and BUFFALOFISHES		
141 BLUE SUCKER	F	*Cycleptus elongatus*
142 BIGMOUTH BUFFALO	F	*Megastomatobus cyprinella*
143 BLACK BUFFALO	F	*Ictiobus niger*
144 SMALLMOUTH BUFFALO	F	*Ictiobus bubalus*
145 QUILLBACK	F	*Carpiodes cyprinus*
146 RIVER CARPSUCKER	F	*Carpiodes carpio*
147 HIGHFIN SUCKER	F	*Carpiodes velifer*
148 MOUNTAIN SUCKER	F	*Pantosteus,* species
149 WHITE SUCKER	F	*Catostomus commersonnii*
150 UTAH SUCKER	F	*Catostomus ardens*
151 SACRAMENTO SUCKER	F	*Catostomus occidentalis*
152 COLUMBIA LARGE-SCALED SUCKER	F	*Catostomus macrocheilus*
153 COLUMBIA SMALL-SCALED SUCKER	F	*Catostomus syncheilus*
154 LONGNOSE SUCKER	F	*Catostomus catostomus*
155 HOG SUCKER	F	*Hypentelium nigricans*
156 RAZORBACK SUCKER	F	*Xyrauchen texanus*
157 LAKE CHUBSUCKER	F	*Erimyzon sucetta*
158 CREEK CHUBSUCKER	F	*Erimyzon oblongus*
159 SPOTTED SUCKER	F	*Minytrema melanops*
160 SILVER REDHORSE	F	*Moxostoma anisurum*
161 NORTHERN REDHORSE	F	*Moxostoma aureolum*
162 EASTERN REDHORSE	F	*Moxostoma macrolepidotum*
163 GREATER REDHORSE	F	*Moxostoma rubreques*
164 GOLDEN REDHORSE	F	*Moxostoma erythrurum*
165 BLACK REDHORSE	F	*Moxostoma duquesnii*
166 RIVER REDHORSE	F	*Placopharynx carinatus*
DACES, MINNOWS, and CHUBS		
167 SACRAMENTO BLACKFISH	F	*Orthodon microlepidotus*
168 CHISELMOUTH	F	*Acrocheilus alutaceus*
169 HARDHEAD	F	*Mylopharodon conocephalus*
170 REDBELLY DACE	F	*Chrosomus,* species

COMMON NAME	OCCURRENCE	SCIENTIFIC NAME
DACES, MINNOWS, and CHUBS (Cont.)		
171 HITCH	F	*Lavinia exilicauda*
172 SACRAMENTO SQUAWFISH	F	*Ptychocheilus grandis*
173 COLORADO SQUAWFISH	F	*Ptychocheilus lucius*
174 COLUMBIA SQUAWFISH	F	*Ptychocheilus oregonensis*
175 BONYTAIL	F	*Gila robusta elegans*
176 GOLDEN SHINER	F	*Notemigonus crysoleucas*
177 SPLITTAIL	F	*Pogonichthys macrolepidotus*
178 FALLFISH	F	*Semotilus corporalis*
179 CREEK CHUB	F	*Semotilus atromaculatus*
180 REDSIDE SHINER	F	*Richardsonius balteatus*
181 EMERALD SHINER	F	*Notropis atherinoides*
182 REDFIN SHINER	F	*Notropis umbratilis*
183 COMMON SHINER	F	*Notropis cornutus*
184 SPOTTAIL SHINER	F	*Notropis hudsonius*
185 MIMIC SHINER	F	*Notropis volucellus*
186 SAND SHINER	F	*Notropis deliciosus*
187 FLATHEAD CHUB	F	*Platygobio gracilis*
188 LAKE CHUB	F	*Couesius plumbeus*
189 RIVER CHUB	F	*Nocomis micropogon*
190 HORNYHEAD CHUB	F	*Nocomis biguttatus*
191 BLACKNOSE DACE	F	*Rhinichthys atratulus*
192 LONGNOSE DACE	F	*Rhinichthys cataractae*
193 BLUNTNOSE MINNOW	F	*Hyborhynchus notatus*
194 SILVERY MINNOW	F	*Hybognathus nuchalis*
195 FATHEAD MINNOW	F	*Pimephales promelas*
196 STONEROLLER	F	*Campostoma anomalum*
INTRODUCED CARPS		
197 GOLDFISH	F	*Carassius auratus*
198 CARP	F	*Cyprinus carpio*
199 TENCH	F	*Tinca tinca*
SEA CATFISHES		
200 GAFFTOPSAIL CATFISH	A	*Bagre marinus*
201 SEA CATFISH	A	*Galeichthys felis*
FRESH-WATER CATFISHES		
202 CHANNEL CATFISH	F	*Ictalurus lacustris*
203 BLUE CATFISH	F	*Ictalurus furcatus*
204 WHITE CATFISH	F	*Ictalurus catus*
205 YELLOW BULLHEAD	F	*Ameiurus natalis*
206 BROWN BULLHEAD	F	*Ameiurus nebulosus*
207 FLAT BULLHEAD	F	*Ameiurus platycephalus*
208 BLACK BULLHEAD	F	*Ameiurus melas*
209 FLATHEAD CATFISH	F	*Pilodictis olivaris*
210 STONECAT	F	*Noturus flavus*
211 MADTOMS	F	*Schilbeodes*, species

Common Name	Occurrence	Scientific Name
LIZARDFISHES		
212 ATLANTIC LIZARDFISHES	A	*Synodus*, species
213 CALIFORNIA LIZARDFISH	P	*Synodus lucioceps*
BLACKFISHES		
214 ALASKA BLACKFISH	F	*Dallia pectoralis*
PIKES and PICKERELS		
215 MUSKELLUNGE	F	*Esox masquinongy*
216 PIKE	F	*Esox lucius*
217 CHAIN PICKEREL	F	*Esox niger*
218 REDFIN PICKEREL	F	*Esox americanus*
219 GRASS PICKEREL	F	*Esox vermiculatus*
MUDMINNOWS		
220 CENTRAL MUDMINNOW	F	*Umbra limi*
221 EASTERN MUDMINNOW	F	*Umbra pygmaea*
KILLIFISHES and TOPMINNOWS		
222 MUMMICHOG	A-F	*Fundulus heteroclitus*
223 STRIPED KILLIFISH	A	*Fundulus majalis*
224 BANDED KILLIFISH	F	*Fundulus diaphanus*
225 CALIFORNIA KILLIFISH	P-F	*Fundulus parvipinnis*
226 STARHEAD TOPMINNOW	F	*Fundulus notatus*
227 VARIEGATED MINNOW	A-F	*Cyprinodon variegatus*
228 DESERT MINNOW	F	*Cyprinodon macularius*
229 GAMBUSIA	A-F	*Gambusia*, species
230 SAILFIN MOLLY	A-F	*Mollienisia latipinna*
231 CAVEFISH	F	*Amblyopsis spelaeus*
NEEDLEFISHES		
232 ATLANTIC NEEDLEFISH	A	*Strongylura marina*
233 CALIFORNIA NEEDLEFISH	P	*Strongylura exilis*
SAURIES		
234 ATLANTIC SAURY	A	*Scomberesox saurus*
235 PACIFIC SAURY	P	*Cololabis saira*
236 HALFBEAK	A-P	*Hyporhamphus* and *Hemiramphus*, species
237 TWOWING FLYINGFISH	A-P	*Parexocoetus* and *Exocoetus*, species
238 FOURWING FLYINGFISH	A	*Cypselurus heterurus* and *Cypselurus furcatus*
239 CALIFORNIA FLYINGFISH	P	*Cypselurus californicus*

	Common Name	Occurrence	Scientific Name
CODFISHES and HAKES			
240	POLLACK	A	*Pollachius virens*
241	WALLEYE POLLACK	P	*Theragra chalcogramma*
242	ATLANTIC TOMCOD	A	*Microgadus tomcod*
243	PACIFIC TOMCOD	P	*Microgadus proximus*
244	ATLANTIC COD	A	*Gadus morhua*
245	PACIFIC COD	P	*Gadus macrocephalus*
246	HADDOCK	A	*Melanogrammus aeglefinus*
247	BURBOT	F	*Lota lota*
248	SPOTTED HAKE	A	*Urophycis regius*
249	MUD HAKE	A	*Urophycis tenuis*
250	SQUIRREL HAKE	A	*Urophycis chuss*
251	SOUTHERN HAKE	A	*Urophycis floridanus*
252	CUSK	A	*Brosme brosme*
253	SILVER HAKE	A	*Merluccius bilinearis*
254	PACIFIC HAKE	P	*Merluccius productus*
TROUT-PERCH			
255	TROUT-PERCH	F	*Percopsis omiscomaycus*
PIRATE-PERCH			
256	PIRATE-PERCH	F	*Aphredoderus sayanus*
OPAH			
257	OPAH	A-P	*Lampris regius*
FLATFISHES			
258	WINDOWPANE	A	*Lophopsetta aquosa*
259	PACIFIC SAND DAB	P	*Citharichthys sordidus*
260	ARROWTOOTHED HALIBUT	P	*Atheresthes stomias*
261	ATLANTIC HALIBUT	A	*Hippoglossus hippoglossus*
262	PACIFIC HALIBUT	P	*Hippoglossus stenolepis*
263	SLENDER FLOUNDER	P	*Lyopsetta exilis*
264	AMERICAN PLAICE	A	*Hippoglossoides platessoides*
265	FLATHEAD FLOUNDER	P	*Hippoglossoides elassodon*
266	ROUNDNOSE FLOUNDER	P	*Eopsetta jordani*
267	SAND FLOUNDER	P	*Psettichthys melanostictus*
268	FANTAIL FLOUNDER	P	*Xystreurys liolepis*
269	CALIFORNIA HALIBUT	P	*Paralichthys maculosus*
270	SUMMER FLOUNDER	A	*Paralichthys dentatus*
271	SOUTHERN FLOUNDER	A	*Paralichthys lethostigmus*
272	GULF FLOUNDER	A	*Paralichthys albiguttus*
273	FOURSPOT FLOUNDER	A	*Paralichthys oblongus*
274	CURLFIN FLOUNDER	P	*Pleuronichthys decurrens*
275	C-O FLOUNDER	P	*Pleuronichthys coenosus*
276	HORNYHEAD FLOUNDER	P	*Pleuronichthys verticalis*
277	DIAMOND FLOUNDER	P	*Hypsopsetta guttulata*

Common Name	Occurrence	Scientific Name
FLATFISHES (Cont.)		
278 LEMON FLOUNDER	P	*Parophrys vetulus*
279 STARRY FLOUNDER	P	*Platichthys stellatus*
280 ROCK FLOUNDER	P	*Lepidopsetta bilineata*
281 SCALYFIN FLOUNDER	P	*Isopsetta isolepis*
282 ALASKA PLAICE	P	*Pleuronectes quadrituberculatus*
283 RUSTY DAB	A	*Limanda ferruginea*
284 MUD DAB	P	*Limanda aspera*
285 WINTER FLOUNDER	A	*Pseudopleuronectes americanus americanus*
286 GEORGES BANK FLOUNDER	A	*Pseudopleuronectes americanus dignabilis*
287 SMOOTH FLOUNDER	A	*Liopsetta putnami*
288 SLIPPERY FLOUNDER	P	*Microstomus pacificus*
289 WITCH FLOUNDER	A	*Glyptocephalus cynoglossus*
290 LONGFIN FLOUNDER	P	*Glyptocephalus zachirus*
291 HOGCHOKER	A	*Trinectes maculatus*
292 TONGUEFISH	A	*Symphurus plagiusa*
SQUIRRELFISHES		
293 SQUIRRELFISH	A	*Holocentrus ascensionis*
STICKLEBACKS		
294 THREESPINE STICKLEBACK	A-F-P	*Gasterosteus aculeatus*
295 TWOSPINE STICKLEBACK	A	*Gasterosteus bispinosus*
296 BROOK STICKLEBACK	F	*Eucalia inconstans*
297 NINESPINE STICKLEBACK	A-F	*Pungitius pungitius*
298 FOURSPINE STICKLEBACK	A-F	*Apeltes quadracus*
PIPEFISHES and SEA HORSES		
299 PIPEFISHES	A-P	Syngnathidae
300 SEAHORSE	A-P	*Hippocampus,* species
CORNETFISHES		
301 TRUMPETFISH	A	*Fistularia tabacaria*
SILVERSIDES		
302 ATLANTIC SILVERSIDES	A-F	*Menidia,* species
303 BROOK SILVERSIDES	F	*Labidesthes sicculus*
304 GRUNION	P	*Leuresthes tenuis*
305 BAY-SMELT	P	*Atherinops affinis*
306 JACK-SMELT	P	*Atherinopsis californiensis*

Common Name	Occurrence	Scientific Name
MULLETS		
307 STRIPED MULLET	A-P	*Mugil cephalus*
308 WHITE MULLET	A	*Mugil curema*
BARRACUDAS		
309 NORTHERN BARRACUDA	A	*Sphyraena borealis*
310 PACIFIC BARRACUDA	P	*Sphyraena argentea*
311 GREAT BARRACUDA	A	*Sphyraena barracuda*
THREADFIN		
312 THREADFIN	A	*Polynemus octonemus*
MACKERELS and ALLIES		
313 WAHOO	A	*Acanthocybium solandri*
314 KING MACKEREL	A	*Scomberomorus cavalla*
315 SPANISH MACKEREL	A	*Scomberomorus maculatus*
316 CERO	A	*Scomberomorus regalis*
317 ATLANTIC MACKEREL	A	*Scomber scombrus*
318 PACIFIC MACKEREL	P	*Pneumatophorus diego*
319 CHUB MACKEREL	A	*Pneumatophorus grex*
320 OCEANIC BONITO	P	*Katsuwonus vagans*
321 LITTLE TUNA	A	*Euthynnus alletteratus*
322 FRIGATE MACKEREL	A	*Auxis thazard*
323 ATLANTIC BONITO	A	*Sarda sarda*
324 PACIFIC BONITO	P	*Sarda lineolata*
325 ATLANTIC TUNA	A	*Thunnus secundodorsalis*
326 BLUEFIN TUNA	A-P	*Thunnus thynnus*
327 ATLANTIC BLACKFIN TUNA	A	*Parathunnus atlanticus*
328 ATLANTIC YELLOWFIN TUNA	A	*Neothunnus argentivitatus*
329 PACIFIC YELLOWFIN TUNA	P	*Neothunnus macropterus*
330 ALBACORE	A-P	*Germo alalunga*
331 ATLANTIC CUTLASSFISH	A	*Trichiurus lepturus*
332 PACIFIC CUTLASSFISH	P	*Trichiurus nitens*
SAILFISHES and SWORDFISHES		
333 ATLANTIC SAILFISH	A	*Istiophorus americanus*
334 FLORIDA SAILFISH	A	*Istiophorus volador*
335 BLACK MARLIN	P	*Makaira mazara*
336 STRIPED MARLIN	P	*Makaira mitsukurii*
337 WHITE MARLIN	A	*Makaira albida*
338 BROADBILL SWORDFISH	A-P	*Xiphias gladius*
DOLPHINS		
339 DORADO	A-P	*Coryphaena hippurus*
SEA BREAMS		
340 POMFRET	P	*Brama raii*

Common Name	Occurrence	Scientific Name
HARVESTFISHES		
341 HARVESTFISH	A	*Peprilus paru*
342 PACIFIC POMPANO	P	*Palometa simillima*
343 BUTTERFISH	A	*Poronotus triacanthus*
RUDDERFISHES		
344 BLACK RUDDERFISH	A	*Palinurichthys perciformis*
JACK, SCADS, and POMPANOS		
345 ROUND SCAD	A	*Decapterus punctatus*
346 HORSE-MACKEREL	P	*Trachurus symmetricus*
347 BIGEYE SCAD	A	*Trachurops crumenophthalma*
348 YELLOW JACK	A	*Caranx bartholomaei*
349 BLUE RUNNER	A	*Caranx crysos*
350 COMMON JACK	A	*Caranx hippos*
351 THREADFISH	A	*Alectis ciliaris*
352 MOONFISH	A	*Vomer setapinnis*
353 LOOKDOWN	A	*Argyreiosus vomer*
354 BUMPER	A	*Chloroscombrus chrysurus*
355 LONGFIN POMPANO	A	*Trachinotus palometa*
356 ROUND POMPANO	A	*Trachinotus falcatus*
357 GREAT POMPANO	A	*Trachinotus goodei*
358 COMMON POMPANO	A	*Trachinotus carolinus*
359 LEATHERJACKET	A-P	*Oligoplites saurus*
360 PILOTFISH	A	*Naucrates ductor*
361 RAINBOW RUNNER	A-P	*Elagatis bipinnulatus*
362 YELLOWTAIL	P	*Seriola dorsalis*
363 BANDED RUDDERFISH	A	*Seriola zonata*
364 AMBERJACK	A	*Seriola dumerili*
BLUEFISHES		
365 BLUEFISH	A	*Pomatomus saltatrix*
SERGEANTFISHES		
366 CABIO	A	*Rachycentron canadus*
PERCHES and DARTERS		
367 YELLOW PERCH	F	*Perca flavescens*
368 YELLOW PIKEPERCH	F	*Stizostedion vitreum vitreum*
369 BLUE PIKEPERCH	F	*Stizostedion vitreum glaucum*
370 SAUGER	F	*Stizostedion canadense*
371 LOGPERCH	F	*Percina caprodes*
372 RAINBOW DARTER	F	*Poecilichthys caeruleus*
373 JOHNNY DARTER	F	*Boleosoma nigrum*

Common Name	Occurrence	Scientific Name
BLACK BASSES and SUNFISHES		
374 SMALLMOUTH BLACK BASS	F	*Micropterus dolomieu*
375 SPOTTED BLACK BASS	F	*Micropterus punctulatus*
376 REDEYE BLACK BASS	F	*Micropterus coosae*
377 LARGEMOUTH BLACK BASS	F	*Micropterus salmoides*
378 GREEN SUNFISH	F	*Lepomis cyanellus*
379 SPOTTED SUNFISH	F	*Lepomis punctatus*
380 YELLOWBELLY SUNFISH	F	*Lepomis auritus*
381 ORANGESPOTTED SUNFISH	F	*Lepomis humilis*
382 LONGEAR SUNFISH	F	*Lepomis megalotis*
383 BLUEGILL	F	*Lepomis macrochirus*
384 REDEAR SUNFISH	F	*Lepomis microlophus*
385 PUMPKINSEED	F	*Lepomis gibbosus*
386 BLACKBANDED SUNFISH	F	*Mesogonistius chaetodon*
387 SACRAMENTO PERCH	F	*Archoplites interruptus*
388 WARMOUTH	F	*Chaenobryttus coronarius*
389 ROCK BASS	F	*Ambloplites rupestris*
390 FLIER	F	*Centrarchus macropterus*
391 WHITE CRAPPIE	F	*Pomoxis annularis*
392 BLACK CRAPPIE	F	*Pomoxis nigro-maculatus*
SNOOK		
393 SNOOK	A-P	*Centropomus*, species
BASSES		
394 STRIPED BASS	A-P	*Roccus saxatilis*
395 WHITE BASS	F	*Lepibema chrysops*
396 YELLOW BASS	F	*Morone interrupta*
397 WHITE PERCH	A-F	*Morone americana*
SEA BASSES and GROUPERS		
398 GIANT SEA BASS	P	*Stereolepis gigas*
399 GRAYSBY	A	*Petrometopon cruentatus*
400 CONEY	A	*Cephalopholis fulvus*
401 ROCK HIND	A	*Epinephelus adscensionis*
402 NASSAU GROUPER	A	*Epinephelus striatus*
403 RED HIND	A	*Epinephelus guttatus*
404 RED GROUPER	A	*Epinephelus morio*
405 YELLOWFIN GROUPER	A	*Mycteroperca venenosa*
406 BLACK GROUPER	A	*Mycteroperca bonaci*
407 GAG	A	*Mycteroperca microlepis*
408 SPOTTED JEWFISH	A	*Promicrops itaiara*
409 BLACK JEWFISH	A	*Garrupa nigrita*
410 SAND BASS	P	*Paralabrax nebulifer*
411 KELP BASS	P	*Paralabrax clathratus*
412 BLACK SEA BASS	A	*Centropristes striatus*
413 TRIPLETAIL	A	*Lobotes surinamensis*

Common Name	Occurrence	Scientific Name
SNAPPERS		
414 GRAY SNAPPER	A	*Lutjanus griseus*
415 DOG SNAPPER	A	*Lutjanus jocu*
416 SCHOOLMASTER	A	*Lutjanus apodus*
417 RED SNAPPER	A	*Lutjanus blackfordii*
418 MUTTONFISH	A	*Lutjanus analis*
419 LANE SNAPPER	A	*Lutjanus synagris*
420 YELLOWTAIL SNAPPER	A	*Ocyurus chrysurus*
GRUNTS		
421 MARGATE	A	*Haemulon album*
422 BLUESTRIPED GRUNT	A	*Haemulon sciurus*
423 RONCO	A	*Haemulon parra*
424 WHITE GRUNT	A	*Haemulon plumieri*
425 TOMTATE	A	*Bathystoma rimator*
426 BLACK MARGATE	A	*Anisotremus surinamensis*
427 PORKFISH	A	*Anisotremus virginicus*
428 SARGO	P	*Anisotremus davidsonii*
429 PIGFISH	A	*Orthopristis chrysopterus*
PORGIES		
430 NORTHERN SCUP	A	*Stenotomus chrysops*
431 SOUTHERN SCUP	A	*Stenotomus aculeatus*
432 SAUCEREYE PORGY	A	*Calamus calamus*
433 LITTLEHEAD PORGY	A	*Calamus proridens*
434 SHEEPSHEAD PORGY	A	*Calamus penna*
435 JOLTHEAD PORGY	A	*Calamus bajonado*
436 GRASS PORGY	A	*Calamus arctifrons*
437 LONGSPINED PORGY	A	*Otrynter caprinus*
438 PINFISH	A	*Lagodon rhomboides*
439 SPOTTAIL PINFISH	A	*Diplodus holbrookii*
440 SHEEPSHEAD	A	*Archosargus probatocephalus*
GIRELLAS		
441 OPALEYE	P	*Girella nigricans*
CHOPAS		
442 BERMUDA CHUB	A	*Kyphosus sectatrix*
MOJARRAS		
443 MOJARRA	A	*Diapterus, Gerres,* and *Eucinostomus,* species
GOATFISHES		
444 SPOTTED GOATFISH	A	*Upeneus maculatus*
445 YELLOW GOATFISH	A	*Upeneus martinicus*

Common Name	Occurrence	Scientific Name
CROAKERS and DRUMS		
446 BANDED DRUM	A	*Larimus fasciatus*
447 SILVER PERCH	A	*Bairdiella chrysura*
448 STAR DRUM	A	*Stellifer lanceolatus*
449 RED DRUM	A	*Sciaenops ocellata*
450 BLACK DRUM	A	*Pogonias cromis*
451 SPOT	A	*Leiostomus xanthurus*
452 SPOTFIN CROAKER	P	*Roncador stearnsi*
453 KING CROAKER	P	*Genyonemus lineatus*
454 ATLANTIC CROAKER	A	*Micropogon undulatus*
455 YELLOWFIN CROAKER	P	*Umbrina roncador*
456 KING-WHITING	A	*Menticirrhus*, species
457 CORBINA	P	*Menticirrhus undulatus*
458 BLACK CROAKER	P	*Sciaena saturna*
459 FRESHWATER DRUM	F	*Aplodinotus grunniens*
460 RIBBONFISH	A	*Eques lanceolatus*
WEAKFISHES		
461 QUEENFISH	P	*Seriphus politus*
462 GRAY SQUETEAGUE	A	*Cynoscion regalis*
463 SPOTTED SQUETEAGUE	A	*Cynoscion nebulosus*
464 SILVER SQUETEAGUE	A	*Cynoscion nothus*
465 SAND SQUETEAGUE	A	*Cynoscion arenarius*
466 WHITE SEA BASS	P	*Cynoscion nobilis*
BLANQUILLOS		
467 OCEAN WHITEFISH	P	*Caulolatilus princeps*
468 TILEFISH	A	*Lopholatilus chamaeleonticeps*
HALFMOONS		
469 HALFMOON	P	*Medialuna californiensis*
SPADEFISHES		
470 SPADEFISH	A	*Chaetodipterus faber*
BUTTERFLYFISHES		
471 BUTTERFLYFISHES	A	*Chaetodon*, species
ANGELFISHES		
472 ANGELFISHES	A	*Pomacanthus* and *Angelichthys*, species
TANGS		
473 SURGEONFISHES	A	*Acanthurus*, species
ROCKFISHES		
474 ROSEFISH	A	*Sebastes marinus*
475 BOCACCIO	P	*Sebastodes paucispinis*
476 CHILI-PEPPER	P	*Sebastodes goodei*
477 ORANGE ROCKFISH	P	*Sebastodes pinniger*
478 VERMILLION ROCKFISH	P	*Sebastodes miniatus*
479 PRIESTFISH	P	*Sebastodes mystinus*

Common Name	Occurrence	Scientific Name
ROCKFISHES (Cont.)		
480 BLACK ROCKFISH	P	*Sebastodes melanops*
481 YELLOWTAIL ROCKFISH	P	*Sebastodes flavidus*
482 RED ROCKFISH	P	*Sebastodes ruberrimus*
483 ORANGESPOTTED ROCKFISH	P	*Sebastodes maliger*
484 COPPER ROCKFISH	P	*Sebastodes caurinus*
485 LONGJAW ROCKFISH	P	*Sebastodes alutus*
486 LOBEJAW ROCKFISH	P	*Sebastodes diploproa*
487 STARRY ROCKFISH	P	*Sebastodes constellatus*
488 CHINA ROCKFISH	P	*Sebastodes nebulosus*
489 BLACK and YELLOW ROCKFISH	P	*Sebastodes chrysomelas*
490 BLACKBANDED ROCKFISH	P	*Sebastodes nigrocinctus*
SCORPIONFISHES		
491 ATLANTIC SCORPIONFISH	A	*Scorpaena*, species
492 CALIFORNIA SCORPIONFISH	P	*Scorpaena guttata*
SABLEFISHES and GREENLINGS		
493 SABLEFISH	P	*Anoplopoma fimbria*
494 COMMON GREENLING	P	*Hexagrammos stelleri*
495 KELP GREENLING	P	*Hexagrammos decagrammus*
496 ATKA MACKEREL	P	*Pleurogrammus monopterygius*
497 PAINTED GREENLING	P	*Oxylebius pictus*
CULTUS CODS		
498 LINGCOD	P	*Ophiodon elongatus*
SCULPINS and ALLIES		
499 IRISH LORD	P	*Hemilepidotus*, species
500 YELLOW IRISH LORD	P	*Calycilepidotus spinosus*
501 BUFFALO SCULPIN	P	*Aspicottus bison*
502 CABEZONE	P	*Scorpaenichthys marmoratus*
503 FRESHWATER SCULPINS	F	*Cottus*, species
504 SHORTHORN SCULPIN	A	*Myoxocephalus groenlandicus*
505 LONGHORN SCULPIN	A	*Myoxocephalus octodecemspinosus*
506 GREAT SCULPIN	P	*Myoxocephalus polyacanthocephalus*
507 SMOOTH SCULPIN	P	*Leptocottus armatus*
508 WOOLY SCULPIN	P	*Clinocottus analis*
509 SEA RAVEN	A	*Hemitripterus americanus*

Common Name	Occurrence	Scientific Name
LUMPFISHES		
510 LUMPFISH	A	*Cyclopterus lumpus*
SEA ROBINS		
511 COMMON SEA ROBIN	A	*Prionotus carolinus*
512 SOUTHERN STRIPED SEA ROBIN	A	*Prionotus evolans*
513 NORTHERN STRIPED SEA ROBIN	A	*Prionotus strigatus*
514 BIGHEAD SEA ROBIN	A	*Prionotus tribulus*
SEA-PERCHES		
515 WALLEYE SEA-PERCH	P	*Hyperprosopon argenteum*
516 BARRED SEA-PERCH	P	*Amphistichus argenteus*
517 POGY	P	*Holconotus rhodoterus*
518 BLACK SEA-PERCH	P	*Embiotoca jacksoni*
519 BLUE SEA-PERCH	P	*Taeniotoca lateralis*
520 WHITE SEA-PERCH	P	*Phanerodon furcatus*
521 RAINBOW SEA-PERCH	P	*Hypsurus caryi*
522 SILVER SEA-PERCH	P	*Damalichthys vacca*
523 RUBBERLIP SEA-PERCH	P	*Rhacochilus toxotes*
524 SHINER SEA-PERCH	P	*Cymatogaster aggregatus*
525 FRESHWATER VIVIPAROUS PERCH	F	*Hysterocarpus traski*
POMACENTRIDS		
526 BLACKSMITH	P	*Ayresia punctipinnis*
527 GARIBALDI	P	*Hypsypops rubicundus*
CICHLIDS		
528 RIO GRANDE PERCH	F	*Herichthys cyanoguttatus*
WRASSES		
529 CUNNER	A	*Tautogolabrus adspersus*
530 TAUTOG	A	*Tautoga onitis*
531 HOGFISH	A	*Lachnolaimus maximus*
532 CALIFORNIA REDFISH	P	*Pimelometopon pulcher*
533 RAZORFISH	A	*Xyrichthys psittacus*
534 SENORITA	P	*Oxyjulis californicus*
PARROTFISHES		
535 BLUE PARROTFISH	A	*Scarus caeruleus*
536 RAINBOW PARROTFISH	A	*Pseudoscarus guacamaia*
GOBIES		
537 LONGJAW GOBY	P	*Gillichthys mirabilis*
REMORAS		
538 REMORAS	A-P	Echeneidae

Common Name	Occurrence	Scientific Name
SAND LANCES		
539 SAND LANCE	A-P	*Ammodytes,* species
STARGAZERS		
540 STARGAZERS	A	*Astroscopus,* species
BLENNIES		
541 KELP BLENNY	P	*Heterostichus rostratus*
542 MONKEYFACE BLENNY	P	*Cebidichthys violaceus*
543 PENPOINT BLENNY	P	*Apodichthys flavidus*
544 GUNNEL	A	*Pholis gunnellus*
545 ROCK BLENNY-EEL	P	*Xiphister mucosus*
546 WRYMOUTH	A	*Cryptacanthodes maculatus*
547 ATLANTIC WOLFFISH	A	*Anarhichas lupus*
548 SPOTTED WOLFFISH	A	*Lycichthys minor*
549 PACIFIC WOLFFISH	P	*Anarrhichthys ocellatus*
550 EELPOUT	A	*Macrozoarces americanus*
551 CUSK-EEL	A	*Rissola marginata*
TOADFISHES		
552 TOADFISH	A	*Opsanus,* species
553 MIDSHIPMAN	P	*Porichthys notatus*
TRIGGERFISHES		
554 COMMON TRIGGERFISH	A	*Balistes carolinensis*
555 QUEEN TRIGGERFISH	A	*Balistes vetula*
FILEFISHES		
556 COMMON FILEFISH	A	*Stephanolepis hispidus*
557 ORANGE FILEFISH	A	*Ceratacanthus schoepfi*
558 FRINGED FILEFISH	A	*Monacanthus ciliatus*
559 LONGTAIL FILEFISH	A	*Alutera scripta*
TRUNKFISHES		
560 TRUNKFISH	A	*Lactophrys trigonus*
561 COWFISH	A	*Acanthostracion quadricorne*
PUFFERS		
562 PUFFERS	A	*Sphoeroides,* species
563 SMOOTH PUFFER	A	*Lagocephalus laevigatus*
PORCUPINE FISHES		
564 PORCUPINEFISH	A-P	*Diodon hystrix*
565 BURRFISH	A	*Chilomycterus schoepfii*
HEADFISHES		
566 OCEAN SUNFISH	A-P	*Mola mola*
567 SHARPTAIL OCEAN SUNFISH	A	*Masturus lanceolatus*
ANGLERS		
568 SARGASSUMFISHES	A	*Histrio,* species
569 BATFISHES	A	*Ogcocephalus,* species
570 GOOSEFISH	A	*Lophius piscatorius*

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INSTRUCTIONS FOR PREPARING MANUSCRIPTS FOR THE TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY

(REVISED 1946)

Please check each item below before the final typing of your manuscript and help your Society reduce the costs of publication, save your Editorial Board (which works gratis) much needless work, time, and expense, and avoid delay in the publication of the *Transactions.*

The following instructions were not drawn up arbitrarily but were condensed from the regulations contained in the best style manuals (Government Printing Office Style Manual; University of Chicago Style Manual). Certain instructions may appear unnecessary, but they are nevertheless essential for the proper handling of materials by the printer and the editor.

I. MECHANICAL DETAILS

1. **Manuscript must be typewritten double-spaced,** including titles, headings, legends for tables and illustrations, and literature citations. Use one side only of sheet. Do not fold manuscript. Write manuscript only in simple upper and lower case. *Do not use all capital letters for any purpose and underscore only when italics are intended.*

2. **Carbon copies will not be accepted.** Do not use thin, transparent paper. Heavy bond paper is preferred.

3. **Margins** at top, bottom, and both sides must be no less than 1¼ inches to allow space for the insertion of directions to the printer and necessary corrections.

4. **Pages** must be numbered in consecutive order, including the literature cited, tables, charts, and photographs. Tables and legends of charts and illustrations must be inserted near their place of reference in the text.

5. **Illustrations.** Make separate pages of tables with headings (not of leader work), of legends of diagrams, charts, and illustrations, and limit the number to those absolutely necessary to clarify or supplement text. *Tables and cuts cost money!* Only sharp, glossy photos can be used. All drawings, charts, and diagrams should be prepared in waterproof India ink on Bristol Board, other perfectly smooth white paper or cardboard, or tracing cloth. Graph paper must not be used. No erasures should be made. Shading should be limited to a minimum and when used the shading lines should be kept open. The curves of graphs should be drawn much bolder than any guide lines or ruling. Lettering should be bold and sufficiently large and spaced apart so that the letters or numbers will not be less than 1 millimeter high or come in contact when reduced. Drawings should be made at least twice the size required for reproduction, and when large should be of proper proportion so that they will not exceed 4¼ by 6½ inches (inclusive of legends) when reduced. All explanatory matter other than the units along each axis of a graph or diagram and those designations needed for clarity should be placed in the legend. The legend, which should be typewritten on a separate sheet, will be set in type below the figure.

Make proper reference in text to all plates, figures, maps, charts, and tables, and designate all of these, except tables, as figures, numbering them in consecutive order with Arabic, not Roman, numerals.

6. **Footnotes** in text should be numbered consecutively and should be placed immediately after the full line of text in which the reference mark occurs, but do not break a line of text to insert footnote. Separate the footnote from the

text by two horizontal lines, one above and one below the note. In each new table footnotes should begin with 1.

7. **The title** of the manuscript, together with the author's name (write out in full either one or both of the Christian names and do not use the word "by"), position or department, and post office address, should always appear at the top of the first page of the manuscript as follows, allowing at least *triple space between lines* to permit the insertion of instructions to the printer.

REPORT ON THE DISEASES OF BROOK TROUT

JOHN EDWARD DOE

Department of Conservation, Lansing, Michigan

8. **Underscore** (italics) all scientific names of genera and species, both animals and plants, in both text and tables. Do not underscore or use all capital letters for scientific names of a category higher than the genus: Esocidae; *Esox lucius. Do not underscore any words unless italics are intended.*

9. Inspect papers in the last volume of the *Transactions* if you have questions concerning the arrangement of materials.

II. STYLE

10. **Bibliographic references** in text should give name of author and year of publication in parentheses, thus (Doe, 1932). Do not use letters or numbers or footnotes for references. If more than one publication by the same author is given for a year, use the alphabet to designate the correct paper, thus (Doe, 1932a) or (Doe, 1932b). In the bibliography do not repeat the author's name if reference is made to more than one of his publications, but list his publications in chronological order beginning with the earliest one. In citing a joint publication invert the name of the senior author but not of the co-author or co-authors. *Do not include any references not mentioned in the text.* List authors in alphabetical sequence. Capitalize the first word and proper names only in the title. Follow the arrangement given below to be placed at end of paper:

LITERATURE CITED

DOE, JOHN C., J. W. BROWN, and H. W. GREEN.
1939. Report on the diseases of brook trout. Trans. Am. Fish. Soc., Vol. 68 (1938), pp. 450-461.

Note that the year of publication precedes the title and the year of the meeting is stated in the reference.

Please check your references carefully as to titles, spelling, capitalization, italics, diacritical marks, abbreviations, etc., against their original sources, after the final typing, and *state beneath your bibliography that you have done so.* Many bibliographic titles published in the *Transactions* have been found to be incomplete and very inaccurate. Help us correct this situation.

11. **Tables.** Every table should have a heading and must be typewritten on a separate page. Insert tables among the text pages near the points where they are discussed. In preparing tables please be certain that they are not too large to appear on a single printed page. Number tables consecutively with Arabic, not Roman, numerals (1, 2, 3, etc.). Abbreviate the word "number" (No.) when referring to a special number—not when referring to quantity or things. Spell all other words in tables, including such words as "millimeters," "ounces," and "average" (except months *with date*, in body of table), and capitalize, as a rule, the first word only in headings in the first column or over other columns. Precede all decimal numbers with zero. Use dollar sign only with first number at top of column and under each cross rule.

Item	Number of fish	Percentage of total	Average length in millimeters	Months	Cost of diet per pound
Brook trout surviving experiment No. 2	23	5.8	6.5	April-September	$0.25

12. **Capitals.** Capitalize words when used as part of a proper name or of an identifying number or letter, or when referring to a particular State, Government, and to organized bodies, or when used as proper names. For example: Lake Michigan, State of Michigan, or the State, the Province, the Republic, or the National and State Governments, Washtenaw County, Ann Arbor Township, Huron River, Pacific Ocean, North Atlantic, Northern States, Reservoir No. 1, Hoover Dam, Pond No. 1 or Pond A, State Fish Farm No. 1, Pisgah National Forest, American Fisheries Society.

Capitalize names of sections of the United States, or of any other country, as Middle West, but use lower case for a term prefixed to any such sections, as eastern North Atlantic States.

Capitalize any term (except page or pages and age group) preceding Roman numerals, as Article I, Chapter II, Sample VI, etc. Also capitalize such terms as Appendix 1 or Appendix A, Experiment 2, Table 4, and Figure 8 (referring to illustrations).

Use lower case for scientific and common names of species. Capitalize scientific names of higher categories.

13. **Abbreviations.**

(a) Abbreviate the following:

Clock time, if connected with figures—2:30 a.m.

Temperatures—F. (Fahrenheit).

Degrees, whether referring to temperatures, longitude and latitude, or angles, etc.—75°, 75° F., 75° C.

"*Number,*" when preceding figures—No. 125; otherwise spell out.

"*United States,*" if preceding name of a department or a bureau or a vessel, etc.—U. S. Department of the Interior, U. S. S. *Indiana.*

Months, in body of tables and footnotes to same when followed by day of month—Apr. 5-Sept. 2 (but April-September).

(b) Do not abbreviate the following:

States, cities, etc.

Months, in text or in headings of tables—April 5-September 2.

Measures and weight, except p.p.m.—6 inches, 20 millimeters, 5 ounces, 1.5 acres, etc.

Percentage—12 percent, a percentage of 25.5.

14. **Numerals.** Spell out all *isolated* numbers less than 10, but use figures in a group of enumerations when any one number of that group is 10 or greater. Do not spell out numbers of two or more digits (except round numbers of approximations: estimated at five hundred; a thousand fish), and always use a comma in a number of four or more digits. Treat alike all numbers in a series of connected groups. For example: There were nine trout. There were 9 trout, 120 bass, and 50 pike.

Use figures for all enumerations of quantities and measurements, such as dimension, weight, area, volume, distance, clock time, time, money, percentage, degrees, proportion or ratios, ages, dates, page numbers, decimals, and mixed numbers (spell out common fractions if alone: one-eighth inch). For example: $3.00 per 20 pounds; 5 feet 6 inches; 10 miles; 6 acres; 15 cubic centimeters; 4:30 p.m.; fish died in 1 hour and 20 minutes; 25.5 percent; 75° F.; 1:10,000; trout 2 years 6

months old; 2-year-old trout; June 29, 1936; the 1st of January, 1938; the 20th day of March; 1937-38; 4.5 p.p.m.; 0.25, 1½ pages; page 215.

Write 8 by 12, not 8 x 12 unless multiplication is indicated. Write 50-50, not "fifty-fifty."

Do not use two figures when two numbers appear together, unless the first enumeration exceeds 100: ten 12-room houses; twenty 6-inch trout; 120 6-inch trout.

Spell out figures beginning a sentence, but avoid such use of numerals if possible. Spell out both numbers of two related amounts at the beginning of a sentence in such expressions as "Twenty to twenty-five trout," but write "Two hundred fifty bass and 325 trout were shipped."

Spell out such indefinite expressions as the following: Between two and three hundred fish; there were thirty or forty thousand trout.

In expressing large numbers the word *million* (or a similar larger group term) may be spelled out: 20 million, 2¾ billions.

15. **Use of hyphen.** Many compound words when used as nouns are not hyphenated but require use of the hyphen when used as adjectives. For example note the following sentences: "This species is adapted to *cold water.*" "Trout are *cold-water* fish." Write "fish culture," but "fish-culturist." Check your manuscript carefully for use of hyphen. The words, "subspecies," "upstream" and many other words originally of compound derivation are written without a hyphen.

Write "largemouth" and "smallmouth" as one word when referring to black bass.

III. SUBJECT MATTER

16. **Condense your paper** to the limit and omit all needless verbiage to reduce cost of printing. The manuscript should be simple, direct, clear, concise, accurate, consistent, and complete. *Accuracy* in subject matter, in scientific names, and in bibliography is especially important. Have your associates read and criticize your paper before the final typing. **Papers which are too poorly written will be rejected.** Do not expect your Editorial Board to rewrite your manuscript.

17. **Be definite in references to species.** The scientific name, and wherever needed the *complete* common name, that will identify the species about which the paper is written should be included in the title as well as in the text, unless the number of species is too large. Such names as "bass," "trout," "pike," and "pickerel" apply to any one of several species. Do not write "smallmouth," "brook," "rainbow," etc., when you mean "smallmouth black bass," "brook trout," "rainbow trout," etc.

18. **Things to avoid.** Words that do not appear in the dictionary in the sense employed should be avoided. The *words* "case," "instance," "show," "found," "gave," and "present" are greatly overworked in manuscripts.

Avoid the repeated use of *participles* which, as a rule, weaken sentences. In the following illustration note the improvement when the words in parentheses are used: "The principles underlying (that underlie) the production of beef are essentially the same as those involving (that are involved in) the production of bass."

Avoid *split infinitives.* Please check your manuscript for this exceedingly common error.

Avoid the use of *this* and *these* as substantives. Compare, for example, the following two sentences for effectiveness: "*This* was true in every *case.*" "*The mortality was high* in every *pond.*"

Avoid the use of a long series of nouns and adjectives as modifiers.

19. **Abstract of paper.** Give a condensed summary or brief abstract at the beginning of your paper.

Prepared by the Editorial Board.
February, 1937 (revised 1946).

INDEX TO VOLUME 75[1]

[1]Exclusive of list of common and scientific names, pp. 353-397.